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Proceedings of the Waste Stabilization/Solidification Workshop

Held at Vegreville, Alberta
November 21 and 22, 1983

Alberta
ENVIRONMENTAL CENTRE

PROCEEDINGS

OF THE

WASTE STABILIZATION/SOLIDIFICATION

WORKSHOP

ORGANIZED BY

ALBERTA ENVIRONMENTAL CENTRE
AND
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FOREWORD

The following proceedings contain texts of the presentations, the discussions, and the opening and closing remarks that were made at the Solidification Workshop held in Vegreville, Alberta, on November 21 and 22, 1984. The workshop program and the list of participants and their affiliations and addresses are also included.

The texts of the presentations were reproduced as received. Unfortunately, not all the texts were submitted, and in nearly all cases, it proved fruitless to transcribe the presentations from the audio recording made. (Frequent reference to slides is a factor.) Hence, these have been omitted.

Some editing was made in transcribing the discussions and the opening and closing remarks. This was limited, however, to deletion of repititious words and "house-keeping" announcements, and to liberal addition of punctuation marks.

We wish to gratefully acknowledge the contributions of those who made the workshop successful and the publication of its proceedings possible. Messrs. Trevor Bridle and Pierre Cote of the Environment Canada's Wastewater Technology Centre conceived the idea of staging the workshop, and put so much work and enthusiasm in all stages of the workshop. The participants in general, and in particular those making presentations and contributions during discussion were obviously responsible for the quality of the contents of the proceedings. The submission of the presentation texts was also appreciated. Last, but by no means least, was the staff of the Alberta Environmental Centre, particularly Connie Gizowski of the Environmental Technology Wing, who in the transcribing process must have acquired new phonetic skills.

B. Anderson
P. Hannak
A. Liem

CONTENTS

	SECTION
Opening Remarks	I
The Regulatory Point of View	II
The Research Aspects	III
Current Experience With Testing Solidified Wastes	IV
Proposed WTC/AEC Protocol and Terms of Reference for the Comparison Study	V
List of Concerns	VI
Open Discussion	VII
Programme and Objectives	VIII
List of Attendees	IX

SECTION I

OPENING REMARKS

Dr. Wilson - Good morning ladies and gentlemen. I am pleased, indeed honoured to welcome such a gathering to the Centre, on behalf of my boss, the Executive Director, and the Management Committee. I hope you have a very constructive time here, that you learn something, that you see that we have some useful work going on and that you feel free to chip in and criticize and correct and contribute in a way that we can all learn. I take no credit for the special effects outside. That is a hazard of being decentralized in north central Alberta and one of the reasons that we rushed into this workshop very soon after its conception. We didn't want to stray into December or January as I am sure you can all imagine what that would have done to our attendance. I think I have to extend a special welcome to new visitors here. We hope that you are pleased with what you see and learn, and that you decide to come back and visit us again. Also I should welcome those who have been before. We are glad to see you again and obviously you enjoyed what you saw last time otherwise you wouldn't have bothered to come again.

I think the response that we have had to this workshop indicates that the subject matter is indeed timely and important. The area of ultimate disposal of hazardous waste has been on the Centre's research priority list since 1975. That was before this facility was built. That priority list was derived by a number of government officials of the province of Alberta, working on program priorities for an institution such as this. The committee was made up of a number of officials from different departments including Agriculture, Energy and Natural Resources as well as Environment. So it shows that it is not only in our area of interest, but it has aspects in other government departments as well.

In 1979, the planning got started for our own waste management program and that was to focus on wastes that were generated from an institution such as this. Those of you who don't know much about our geography, will perhaps not realize that we don't have much water here. We have a lot of land, we don't have much water so we have to take special precautions in disposing of our own wastes. So, that program planning started in 1979 and got underway in 1980 when the building first opened. The program consisted of disposal of our laboratory wastes through waste water treatment prior to discharge to the local sewer system; incineration program for organics; and finally collection of the solid

wastes for landfilling. That program is still underway and each year we are adding a bit to it. We are going to be running our new incinerator later this year, and this is developing into an experimental incinerator which will allow us to study incineration of waste mixtures and products of partial combustion. But it will also provide us with some solid residue which we will have to dispose of, which we can use as material for our experimentation in disposal technology.

In the last three years or so the interest in what we are doing here has grown, not only in Alberta, but across Canada and it's a real pleasure to see that people have travelled a great distance here to listen to some of the things that are going on. As most of you know, the province is committed to building and having operational in this province, special waste disposal facilities and some of the staff from here have participated in educational forums that were part of the siting committee's work during the time when the public of Alberta was being asked to consider to have a special waste facility site in their areas.

One of the most often asked questions was "What is the fate of materials that go into landfill sites?" "How much is known about it?" There was obviously a large amount of public concern. At the request of Dr. Seifried, who is in the audience, we have broadened our program here to include studies of materials that are landfilled. Particularly materials that are landfilled after solidification. We feel this is a response to genuine concerns in the public of Alberta and elsewhere as well. We hope that this program here will go a long way to allaying some of the fears and concerns.

Earlier this year we met with Dr. Bruce Jank and Trevor Bridle of the Water Technology Centre to discuss, explore areas of common concern and I was very pleased to see that this workshop was one of the results of that meeting. Both Trevor and Albert Liem have done a great deal of work to put it together and I am happy to see that they were really timely with the program. During the next couple of days I expect to hear some very important exchanges of information and I know that several very distinguished people sitting in the audience have the same kind of expectations.

Seeing such a distinguished audience reminds me of the last time when I was in Ottawa when I had the privilege of attending a banquet at the Chateau Laurier. It was one of these very refined banquets where everybody was dressed up to the "nines": long gowns and penguin suits and so on. I was also very privileged to sit next to a young lady who was really a lady, English Lady and she was obviously very refined, covered in diamonds, what you might call over nourished and under clothed, and toward the end of the event, after the dinner was over, she leaned back in her chair a produced a huge Havana cigar. I thought, what luck, I'm going to get a good smoke. But no it wasn't for me, unfortunately, she expertly snipped the end, warmed it with a lighter and then started to puff away. I was intrigued by this, seeing such a refined person on the end of a huge Havana cigar. I leaned over and said, "Excuse me, I am very interested to see you smoking such a nice cigar, how long have you been smoking cigars like this?" She whispered, "Since my husband found one in the ashtray". I think without further ado I should hand over to another distinguished person from Ottawa, Dr. Salloum. Once again welcome to the Centre. I hope you have a productive workshop.

Dr. Salloum - Thank you very much Dr. Wilson. It is a useful thing when you are arranging things of this type if you can arrange to be the second opening remarker because then you can say the time is all used up, it's a quarter to nine and let's get started, or you can say as I am going to do: I enjoyed your opening remarks and I agree with everything you said except that last story. This is a personnal first for me. This is my first visit to the Alberta Environmental Centre. I hope it won't be my last. We have, in the Technical Services Branch of Environmental Protection Service, a very simple philosophy as far as technical co-operative projects are concerned. By and large we believe that there is never enough money or enough time or enough people to do all the work that needs to be done in the areas of concern that we are involved in, so we will happily collaborate with just about anybody you want to name in terms of co-operative technology projects. High on our list of those we would like to co-operate with is the Alberta Environmental Centre, EPA and various EPA contractors. Did I miss anybody? Trevor and I are not quite good friends this morning. Trevor is one of my more able people at Burlington and I am pleased that he is in the operation, but don't ever ask him to estimate a distance for you. This morning when I was having breakfast with him, I said,

"How far is the Centre?" and he said "Oh, it's just a quarter of a mile". I like to get a walk in the mornings anyway. I went out there and I turned left and normally I can walk a mile in about 25 minutes. So I walked for about half an hour and I said, "Where is this place?", and I started looking and I ended up way down here. And when you are at the driveway Trevor, turning off the highway, you are still a quarter of a mile away.

The technology of ultimate waste disposal is one that we don't have enough handles on. It is one that we are all going to have to do a little work on and we are all going to have to come up with some agreed positions as to how these things are done. I am delighted to see such a group of experts, assembled in one place for the study and consideration of one specific technology which, despite the fact that it has been around for awhile, not as much is known about it as we would like to see. However we will all know more about it by noon tomorrow and I would encourage and I know we will get the most active possible type of participation. Everybody here is in a position of knowing a fair amount about this subject and if we can add that all together and divide by the number here we will all end up knowing more when we are done. Congratulations and let's go.

SECTION II

THE REGULATORY POINT OF VIEW

Bob Lane - Welcome to the day after the Day After. I don't know which depressed me most: watching that movie last night or getting a message that I had a 7:00 breakfast meeting. Welcome to the first session, entitled The Regulatory Point of View. We have four speakers this morning and they are welcome to sit up front where people can see them. I think that at the very least when they have finished speaking they should perhaps sit at the front so that they can entertain questions, immediately after their talks or at the end of all four. I have been asked to say a few words about the basic differences between the regulatory aspects of the topic of this conference. Differences between United States system and Canadian system. We have two speakers from Canadian provinces. We have a speaker from the U.S. federal government and a speaker from the Canadian federal government so obviously I am not going to spend a lot of time on this, although I have been asked to make it clear to you and to those that may not appreciate this. In the United States the federal government plays a far more important regulatory role in regard to this subject, as well, and I am sure it is safe to say, other environmental subjects. The Resource Conservation and Recovery Act enables U.S. federal government to play a stronger role and I am sure we will hear more about that this morning. In Canada, where constitutionally the provinces manage the natural resources, the Canadian federal government plays a much less important role in the regulatory aspects. The federal government in Canada does play a stronger role perhaps in the technological and research support to the regulatory agencies. There are a couple of federal acts in Canada that enable the federal government to participate in regulation and these are the Environmental Contaminants Act and the Transportation of Dangerous Goods Act. I'm sure we will hear more about that perhaps from our first speaker. That being said, I am looking forward to hearing what these folks have to say and so I think I'll turn it over to the first speaker Valerie Douglas from The Environmental Protection Service.

WASTE SOLIDIFICATION - FEDERAL REGULATORY ASPECTS

Valerie M. Douglas
Waste Management Branch
Environment Canada

The management of hazardous wastes in Canada rests primarily with the provinces, however, there is a need for a strong federal role in the development of technologies, the development of guidelines for uniform basic standards across Canada and the development of a monitoring and control system for interprovincial and international movement of wastes.

This federal role was recognized by the Canadian Council of Resource & Environment Ministers (CCREM) and subsequently the Federal/Provincial/ Territorial Committee on Hazardous Waste was formed with the aim of coordinating the development of a national program for the management of hazardous wastes.

Some of the pressing issues of waste management in Canada are being addressed by DOE as follows:

1. The finalization of regulations for the transport of hazardous wastes under the Transportation of Dangerous Goods Act, 1980 (TDGA) incorporating such components as: hazard criteria, waste definition, classification, and listing and national uniform manifest requirements.

2. The identification of existing and abandoned waste sites; a program currently being undertaken by a series of joint federal-provincial projects. Memoranda of Understanding have been signed by most jurisdictions on a 50/50 cost sharing basis, and a three-phase project is under way to identify those sites which pose a potential threat to man and/or the environment.

3. The support of the development of a regional approach to hazardous waste management by -

   - technical support to provinces;
   - considering the sale of federal lands to the provinces;

- participating in regional inventories of hazardous waste generation;
- support of the development of regional hazardous waste disposal treatment/disposal centres.

4. The encouragement of waste reduction/recycling as a component of good waste management practice.

5. The development of waste disposal and treatment guidelines via:

   - research and technology development
   - demonstration
   - technology transfer.

The overall goal is to achieve national uniformity in the approach to waste management in Canada.

About three (3) years ago, the Federal/Provincial/Territorial Committee on Hazardous Wastes appointed two working groups, one on Hazardous Wastes Criteria and Lists and one on Hazardous Waste Manifest, to assist in the development of regulations for the transboundary control of hazardous wastes.

The Regulations under the Transportation of Dangerous Goods Act define and list dangerous goods as well as hazardous wastes as a subset of these dangerous goods. Furthermore, this Act outlines the requirements for the transportation, packaging, labelling and manifesting of these wastes.

The TDGA regulations, have been published in Canada Gazette No. 1, for initial comment and are expected to be published in Canada Gazette Part II early in 1984. These regulations apply primarily to the handling and transportation of dangerous goods/hazardous wastes, however, the ultimate destination is controlled via the manifest and this, coupled with the designation of hazard will contribute to the protection of the environment from hazardous wastes.

The Federal/Provincial/Industry Working Group on Hazardous Waste Criteria and Lists is currently developing hazard criteria to demonstrate whether or not

a waste is hazardous. This will aid in the decision to list or delist wastes from the TDGA regulations' list.

Hazardous wastes are those which are:

a) hazardous based on hazard characteristics (criteria)
b) specified waste streams in TDGA Unit I regulations
c) discarded dangerous goods as listed in TDGA Unit I Regulations.

Since the toxicity hazard of complex mixtures is hard to specify it was decided that the toxicity of individual components may render wastes hazardous. Currently the Working Group is examining the chronic toxic effects of wastes such as carcinogenicity, teratogenicity and environmental hazards such as bioaccumulation and persistence. The question of leachability and mobility of hazardous components is also under serious consideration by the Working Group.

One of the future tasks of the Federal/Provincial/Industry Working Group on Hazardous Waste Criteria and Lists is the review and assessment of the treatment and disposal options for hazardous wastes. The assessment will evaluate the effectiveness and validity of technologies, including waste solidification, which are aimed at reducing the hazards from waste disposal.

In the future the Working Group will review various wastes and recommend their inclusion or deletion from the hazardous waste list of the TDGA Regulations; this impacts on solidification the following way:

a) a waste may be designated non-hazardous and thus will not need any special treatment;

b) a "solidified" waste that is shipped off site (such as a dewatered waste) may be deemed hazardous.

Of course most solidified wastes probably will not be transported and thus will not be affected by TDGA. However, any potential threat posed to man or the environment must be anticipated so that those threats could be reduced or eliminated.

The most likely problem, as far as the environment is concerned, is the potential for pollution due to the failure of the solidifying matrix. Therefore any solidified material must be subject to rigorous testing prior to land filling to ensure that any leachate formed does not pose an environmental or health threat particularly via the ground water. Furthermore other precautions should be put in place such as leachate monitoring systems. Since this is such a new technology, there is much to do and much to learn.

This department, then, can offer its resources to encourage the development of this promising technology, aid in the assessment of environmental and health effects, provide national leaderships for analytical research, and technical developments and in general, act as a focal point in the dissemination of this vital information.

DISCUSSION

B. Lane - Thank you very much. I think we may as well entertain questions now if you have them and bearing in mind that you won't get off the hook if there are no questions now because we'll have a session later. Any questions from the floor? I was wondering when I introduced you or when I made my introductory remarks I was guilty of passing over the fact that in fact the federal government in Canada does have a large stake in this country in the Northwest Territories where there are no provinces, not yet, and I wonder if you might care to say something about the distinction between the federal in the north and the federal role in the south.

V. Douglas - Well, as far as demonstration of technology is concerned, of course, that role will be uniform across Canada. I feel that, and I can only speak for myself, you probably have a better understanding of this, the federal role is wherever the provincial or territorial governments care to call in the federal government to assist them with the hazardous waste treatment and hazardous waste management problems. But ultimately I think that each province is going to be handling its own unless they request assistance, or the federal role right now is only for federal lands. We are doing a number of interesting projects. I think that you probably know about the abandoned waste disposal site program where we have entered into agreement with provinces to identify abandoned waste disposal sites. This is one important project whereby, again, the federal government is participating on a cost sharing basis in identifying waste disposal sites. The ultimate clean-up of these sites is going to rest with the waste generator, if we can find them, or otherwise there will have to be some means of finding funds for areas of national concern. Another federal provincial program is in inventories of hazardous waste generation, again the federal government has entered into agreement with the provinces to identify the inventories of hazardous wastes. The federal government is also considering the sale of lands, crown lands, to demonstrate technology as well as to provide potential sites for a waste disposal such as the one in Blainville in Quebec where there is a waste solidification site by Stablex.

ENVIRONMENTAL ASSESSMENT OF WASTE SOLIDIFICATION
REGULATORY POINT OF VIEW

David Friedman
Office of Solid Waste
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INTRODUCTION

Under the Resource Conservation and Recovery Act, the U.S. Environmental Protection Agency (EPA) is responsible both for a nationwide program to identify wastes which, if improperly managed, pose a substantial hazard to human health or the environment and to establish minimum standards for the management of such hazardous wastes. In accord with this mandate, EPA has published regulations identifying the characteristics of hazardous wastes, listing hazardous wastes, and established management standards for such wastes. In addition, EPA has established criteria by which generators or other persons may demonstrate that a waste does not pose a hazard and thus should not be regulated as a hazardous waste.

The regulations promulgated by EPA to implement RCRA, require that the storage, treatment, and disposal of hazardous waste be carried out in accordance with a permit issued by EPA or an authorized state. Stabilization or fixation of hazardous waste with the aim of either making the waste more manageable or non-hazardous is thus an activity subject to the RCRA regulations. Owners and operators of facilities not in existence in 1980, when the initial regulations were promulgated, must apply for and receive a permit before beginning operation of such a facility.

Several processes for treating inorganic type waste involve treating the wastes with a variety of additives to render the waste's inorganic constituents relatively immobile in the environment. Among the processes thought to be successful in achieving a low mobility of inorganic constituents are the chemical fixation processes.

At this time I would like to digress for a minute and clarify how I will use some common terms in my discussion.

Solidification: Solidification processes are those that act to change the physical characteristics of a waste in order to improve its handling characteristics. Usually this includes changing the waste from a liquid or sludge to a soil-like material which can be handled with earth moving equipment. Solidification usually also results in a decrease in material permeability and thus a decrease in leachability.

Stabilization: Stabilization processes are ones that treat the waste in order to reduce the mobility or leachability of the toxicant. They do not necessarily render the waste non-hazardous. They do not necessarily result in a change in the waste's physical characteristics.

Fixation: I use fixation to refer to the highest form of treatment. It is thus those processes by which a waste material is treated such that the leachability of the hazardous components in the waste are rendered low enough for the waste to be delistable.

From a regulatory perspective, why is such treatment important?

Listed hazardous wastes which have undergone any treatment process are still considered hazardous unless an exemption has been petitioned for, and granted for that specific treatment residual. The process of excluding a particular waste from the hazardous waste category is euphemistically called "delisting". The process is considered to be a modification of the original listing determination and is, therefore, treated as an amendment to the lists of hazardous waste. Only wastes which are hazardous by reason of listing are so affected. Wastes which are hazardous by reason of the "characteristics" do not have to go through the "delisting" process. Such wastes automatically cease to be hazardous wastes when the treatment is sufficient for them not to exhibit the property for which they were originally hazardous.

A second aspect of waste treatment that is important to us revolves around actions being considered by the Congress in their RCRA reauthorization activities. The House of Representatives has already passed and the Senate is

considering instituting a ban on the landfilling of all hazardous wastes unless EPA determines that one or more methods of land disposal are sufficient, for that waste, to protect human health and the environment. Prohibitions are to be based on the waste's attributes of persistence, toxicity, mobility, and propensity to bioaccumulate. With respect to inorganic toxicant containing wastes, persistence, toxicity, and propensity to bioaccumulate remain forever. Thus, mobility, since it is the only property that is amenable to modification is a very important property. The processes we are here to discuss offer a means of reducing the mobility of the toxic elements in order that such wastes may be landfilled safely.

A third benefit of waste treatment concerns the design of facilities that dispose of treated wastes. Even though some treatment processes do not result in a non-hazardous waste, improvement in the physical properties of the resulting material can greatly simplify the design of the landfill and thus the solidification processes may be of value.

What properties of the treatment process and residue are important from a regulatory point of view?

With respect to the questions of "delisting" and suitability for land disposal, the Agency's concerns relate to the availability of the toxic constituents, the effect of environmental and handling stresses on the materials, the stability of the material over very long periods of time, and thus the degree of control that would have to be exercised over the disposal site to insure that no unacceptable uses of the site occur.

Specific properties that are important are: leachability of the freshly prepared and fully "cured" material under a variety of conditions, physical stability of the material after long-term exposure, effect of long-term exposure on leachability, sensitivity of the material to weathering (e.g., freeze thaw cycles, acid rain, continuous long-term leaching, oxidation) and sensitivity of the material to co-disposal with other wastes.

In designing land disposal facilities however, additional properties become important, including durability, permeability, handling characteristics, compactability, and load bearing strength.

How does EPA presently evaluate a treated waste to determine if it is a hazardous waste?

Fixation is a process whereby toxic constituents of the waste are immobilized and thus prevented from being released into the environment. It does not destroy the toxic species. The focus of our evaluation thus hinges on determining that the material is in fact not likely to release any harmful species into the environment even under conditions of reasonable improper management. In conducting such a review, EPA evaluates the following factors:

- what hazardous species are present in the waste;
- what is the likelihood of release under various management conditions;
- how best to evaluate the potential releasability of the species that are present.

These last two points are worth discussing. Once the hazardous components have been identified, the next problem is to determine what form of reasonably improper management is of most concern. For example, certain wastes pose more of a potential hazard if managed in an alkaline environment than if managed in an acidic environment. Other wastes contain relatively volatile compounds and thus evaluation of the potential for air contamination is more critical than evaluating potential for leaching. After the appropriate mismanagement scenarios are determined, test methods can be selected to evaluate the release potential.

The evaluation of delisting petitions is handled on a case by case, facility-specific basis. The Agency has not yet established specific thresholds, at which a waste is not hazardous, for those properties that are of concern. Instead, the properties of the waste along with its potential for mismanagement, and the type of mismanagement that may be encountered are evaluated in arriving at a decision.

The most important property with respect to land disposal however is potential toxicant leachability under various scenarios. In order to conduct its evaluation, EPA has developed several leaching tests for use in characterizing wastes. These are the Extraction Procedure, the Multiple

Extraction Procedure or Acid Rain Extraction Procedure, and the Oily Waste Extraction Procedure. In addition to evaluating the potential for leaching, EPA also considers the presence of other toxic species that may pose a problem through other routes (e.g., air contamination).

At this time I will briefly describe some of the members of the Extraction Procedure family.

Extraction Procedure

The Extraction Procedure, or EP as it is commonly known, was designed to serve as a means of identifying wastes which should be regulated as hazardous waste because they present a potential hazard to ground water. For purposes of this characteristic the Agency decided to employ a co-disposal scenario as a reasonable form of mismanagement. Thus, the EP was designed to model the leaching action a waste might undergo if disposed of in a sanitary landfill. The EP does not always model the worst case disposal situation however. For example, with respect to treated wastes, it does not identify those wastes where the low mobility is due to a material, present in the wastes, which will slowly leach out and thus free up the toxic agent for later leaching. This particular scenario is the subject of the Multiple Extraction Procedure.

Multiple Extraction Procedure

A continuing question with treated wastes is the long term stability of the material. The concern is that the "additive" responsible for the lowered mobility is fugitive and will gradually leach out of the waste. Once that happens, the hitherto non-mobile toxicant will begin to leach out. In order to evaluate wastes for this property, EPA employs the Multiple Extraction Procedure or MEP. The initial step in the MEP is the same as in the EP. In the MEP however the waste is then sequentially extracted with fresh extractant. Extraction of the waste is carried out eight times. It is currently our belief that any waste which does not exhibit increased leachability after eight extractions is unlikely to lose its low mobility under any reasonably plausible environmental conditions. The MEP uses a simulated acid rain for the second through eighth extractions instead of the acetic acid solution used in the EP and initial extraction. Oily Waste Extraction Procedure while not generally

applicable to the area of treated wastes, one additional mobility procedure of interest is the Oily Waste Extraction Procedure (OWEP).(sic) This procedure is used to evaluate the potential mobility of metals from wastes that contain significant amounts of oils and greases and which are to be managed by land treatment or land disposal. It employs a sequential soxhlet extraction of the waste using tetrahydrofuran and xylene. After the organic matter is removed, the remaining solid material is subjected to the EP procedure. The OWEP is designed to simulate the degradation effect of biological action on the waste and the resultant enhanced mobility of the metals. Removal of the oil and grease prior to running the EP is necessary because the oil and grease prevents wetting of the solid.

In addition to the mobility procedures already mentioned, other test procedures used to evaluate the potential for environmental harm include a neutral extraction test for leachable cyanide and a cyanide/sulfide reactivity test. In addition, for fixated inorganic wastes, the concentration of organic matter is considered to be important since organic compounds can both interfere with the fixation reaction and eventually change the properties of the waste once they degrade.

Where do we go from here?

Given the overriding concerns with the impact of land disposal of hazardous wastes, it is going to be of critical importance that we obtain a better understanding of how treatment processes work. It is only when we, on a scientific basis, are in a position to convince the public that we really know what is going on will they be confident that our short-term tests are acceptable indicators of what will happen long in the future.

Thus, from a regulatory point of view, we need to know:

- what chemical bonds, if any, are being formed that result in lessened toxicant mobility?
- what is the long term stability of these bonds?
- what effect will various materials that may be present in the waste have on the formation and stability of the bonds (e.g., interfere with curing, decreased stability)?

- what properties, of the treated waste, are important to insuring that uncontrolled disposal of the material will not result in damage to the environment, or conversely, what regulatory controls are needed to insure safe management?

Future activities, however, are aimed at answering these questions in order that the Agency's waste evaluation standards can be made more objective.

DISCUSSION

P. Chaudhuri - Quite interesting the distinction you made between stabilization and fixation. I wonder if you could give us some examples of the distinction for organic or inorganic wastes.

D. Friedman - One company in the United States has just developed a process to treat some organic sludge, this is a chlorinated organic sludge material that has been generated over a number of years and this material has low bearing strength. It's a big problem and they have found a way of solidifying that material and turning it into an earthen like material which can be easily managed and handled. Now, there is no thought in this process, and they make no claims, that this has done anything to address the leachability of this material. There is no type of bonding that is thought to be occurring that's going to lower the mobility other than just when you do compact this material you lower the permeability, so you get that kind of advantage - as opposed to many of the processes people have come into the agency with, that said they have added chemicals to an inorganic waste which formed chemical bonds which dropped the mobility; as opposed to, for example, a lime treatment where you are just basing it on a change in solubility. So that is what I meant.

C. Wiles - I guess, I understand the difference between your definitions on solidification and chemical fixation but I didn't catch your differences between solidification and stabilization.

D. Friedman - O.K. Solidification, I'm just using to mean when you've changed the physical properties of the material; it's for convenience in handling. In general probably almost anytime you've done that you've ended up lowering the leachability, the mobility of the materials, because as I said usually the permeability goes down. The main difference between the other two processes, namely stabilization and the fixation process is just in the degree. In other words, and this I think will become more important later in the United States when people may have a process that is good enough to make the materials suitable for land disposal but we still feel it needs professional management. In the United States, need for professional management means a hazardous waste. That's really what the term hazardous waste means, it means that this waste

still has properties which require it to be professionaly managed. So I just normally use the term fixation when I want to refer to something that has gone to such an extent that we now can remove it from regulatory control.

C. Wiles - I guess where I'm coming from chemical fixation does do something to tie the material up with chemical bonding or something very similar to that and I consider that to be a class by itself. Solidification could do what you talked about before; doing nothing but converting it to a soil like material which makes it easy to handle. Stabilization to me may involve both of those processes.

D. Friedman - Correct. They're not exclusive.

C. Wiles - I just wanted to clarify, you're not excluding one from the other when you're talking about stabilization.

D. Friedman - No, probably every fixation process that I know of is a solidification process. I'm trying to think if there are any that are not, that I can think of. So it's usually to what degree are you trying to accomplish something with where you are. I'd rather not dwell too much on this because I know it's a topic we're going to cover in these two days to see if we can come up with common terms of these materials and that's why I just wanted to make sure that, at least when I'm talking, you know what today I mean when I talk about these terms and hopefully maybe before we leave we can all use the same terms, whatever we may decide they may be in this field.

J. Conner - Two questions, Dave. First, has the oily waste extraction procedure been published and if so when and where, or officially written up?

D. Friedman - Its been officially written up and has not been published. Basically whoever has a need for it, we just send them a copy.

J. Connor - Second, where are you with regard to establishing terrestrial limits, if you like, or limits such as the limits that have been established for metals with other constituents such as other inorganics and organics especially?

D. Friedman - O.K. That's not exactly the subject this afternoon. One area of the regulatory program that is very active right now is to expand the characteristics to include organic materials, and this has been termed the organic toxicity characteristic and what we hope to do within the next six months is to propose in the federal register a definition which would say: If a waste contains any of the following materials at concentrations above such a level (And these would be organic materials, and our guess is, we will probably come out initially with about thirty organics, these would be highly toxic compounds, carcinogenic materials), the waste would be hazardous. So if it contains any of these materials at this level or greater, it's hazardous. At the same time, as many of you know we have had a program underway at the Oakridge National Laboratories to develop an extraction procedure for organics. The carbon extraction procedure is really not designed to handle organic materials. It may, but it's just we don't know how good it is and they've been charged with developing an extraction procedure, second generation test which would be suitable for organics. We hope to, sometimes towards the latter part of 1984, propose what we have euphemistically termed EP3, which is this procedure. And the reason there is no EP2 is, it didn't work; it's as simple as that. We had two concurrent programs going, one quickly turned out to be a dead end so we dropped it, but we continued the EP3. So we hope at that time towards the end of, around the fall or winter of 1984 to propose this EP3 and the thresholds for these organics that would be in the EP3 extract. And depending on the response of the public to the proposed test, we may be able to just go directly to the EP3 and its thresholds and not promulgate as final regulations the thresholds in the waste itself. Also that depends on the work continuing to go successully in the laboratories on EP3. So that's where we stand with that.

M.A. Wilson - I'd like to ask Dave if any consideration has been given to evaluating a test for microbial stability of some of these materials?

D. Friedman - Yes. One concern that we have had, at least I have had, is how do we determine the persistence of organic materials once they have been put into the land. And hopefully one of these days we'll have a breathing spell that we'll be able to try to work on that problem, but it is one that we've been trying to get to for about three years and we just, I'm not supposed to say, we're short of resources but, we're not flush.

L. Katsanis - We talked a little bit about EP, MEP, OWEP and all those tests. How do you use this in the listing procedure. In other words, this is my confusion a little bit. We talk about specific thresholds not having been identified or established, yet we go ahead and do these tests. How do you correlate one to the other?

D. Friedman - Generally, the first question you have is with the EP. If you have values in the EP that are greater than about 30% of the current EP thresholds, then save the paper, don't bother with a delisting petition. At that point, as I mentioned before it's a case by case decision, where, when you apply for, you send in and petition the delisting program; the people in the delisting program look at the material, kinds of processes that are going on, for example if you had some type of encapsulation process where you, what I usually term, gift wrap it in a polymer. Which is like polyethylene or something like that, you probably would not bother with any of these leaching tests because it's of another concern. While if it's something that we think may be susceptible to the additive that's resulting in the lower mobility coming out, then we will want to stop using the multiple extraction procedure. And as I mentioned the oily waste extraction procedure is where you are dealing with materials that have high hydrocarbon contents.

L. Katsanis - The next question is: Is there a place where all what you just discussed is in writing where someone can pick up and see the thought processes that go through, so that they can try and do their testing to fit your demands, because its kind of difficult to have to guess what you folks are thinking?

D. Friedman - No. The delisting people are in the process of putting together a federal register notice and a draft of that was put together before I had left Washington and it's going through the agency. To explain how we're approaching delisting currently, and one thing I should mention; there has been a very significant change in the way we evaluate delisting petitions over the last couple of weeks. Up until then we have a part of our regulations which gives the reason why each particular hazardous waste is considered hazardous. For example with a refinery waste such as an API seperator sludge, the reasons for its listing is because it contains lead and chrome. And initially if you

want them to be delisted all you had to show was that that particular waste did not contain hazardous levels of lead or chrome or that they were going to be nonavailable to the environment. That philosophy has changed totally in the last couple of weeks so that now if a waste is hazardous, to get it delisted one must demonstrate that it has no hazardous properties of concern. So that the organics, for example, would have to be evaluated also. And this goes for all wastes. So this federal register notice should spell that out clearly, what that's all about. Hopefully, as I mentioned in my remarks, we will start getting more objective standards as we develop things like the organic toxicants, characteristic EP3, and so on. We will be able to establish thresholds for both when a waste is hazardous, and when it's hazardous what can be landfilled and what can't be landfilled. And this is an area that, especially the one with the standards on land disposal on it, (when it can be land disposed and when it cannot be) is one of an extremely high priority project with us right now and this is why this particular workshop that has been setup by Canada is so critical to us in trying to help us better formulate our policies.

P. Malone - I just have one quick observation. First, Nuclear Regulatory Commission has recently published a sort of an inhouse paper on their own ideas of what a low level nuclear waste solidified product should look like and they included within it a discussion of the biological degradability, and how to test for it inside an ASTM procedure, for looking for the number of colonies growing on the surface. So this is one hopeful beginning on that degrading problem. The other question I wanted to pose was a little scenario where there is perhaps one little loop hole that we've missed on the testing procedure, and that is, a very soluble material available in the waste in a relatively dilute form. Suppose for example I were to take something like sodium fluoride or potassium cyanide which is very hard to hold on to and I put it in the waste in very small quantities. Now I put this waste in a landfill and the landfill operator takes great care to minimize the amount of water coming through. While there may be the toxic constituent at a very low concentration, its very soluble. He minimizes the water getting through, this assures that there's enough of a very soluble material to produce eventually a very toxic concentration of that particular type of soil. In our testing procedure we always use fixed amounts of wastes versus fixed amounts of liquid. We can't really come up with that scenario where there is that possibility that the waste, its very soluble phases

will in fact be in equilibrium and will eventually reach concentrations which are very high in toxicity. So there is another possibility for an additional testing protocol.

D. Friedman - Well, one of these kinds of concerns that you're bringing up is one that we're grappling with on the EP3 program which gets into, for example, the situation where you have small amounts of a toxic species in the waste and as Phil mentioned it's quite soluble. You may have a high instantaneous concentration, for example taking place in this landfill, but our thresholds are generally based on chronic exposure. Now there's lifetime exposure or at least decade long exposure of people to the water. If you have only very short periods of exposure, you should be using different kinds of thresholds and how do we juggle these thresholds versus exposure time is one of the biggest problems we're facing in the EP3 work.

THE REGULATORY POINT OF VIEW

R. Gotts
Waste Management Branch
Ontario Ministry of the Environment

Thank you, Mr. Chairman, it's a pleasure to be here in Alberta. I guess we were asked to talk about Waste Stabilization, Solidification, Fixation, or whatever you wish to zero in on, under the general areas of philosophy, current regulations, future prospects and regulations, and level of public participation in the exercise.

In Ontario we think waste stabilization is a good role and that's our philosophy. We currently don't regulate waste stabilization at all. We don't plan to in the future and we've told the public about it. On a more serious note, this is a timely exercise for us. Some of you may be aware that in Ontario we just recently in June of 83' published a blueprint for waste management in the 80's. What we have decided to do, having been in the business of regulating waste management for about 10 or 12 years, was take an inventory, look at everything we do, decide what we've done right, what we've done wrong and where we had some holes and to put forth proposals as to where we thought we should be going in the 80's. Basically for the first time, on such a scale anyway, we significantly involved the public in the exercise and we have just been in the process of doing that. We completed our last formal public meeting just at the end of October and we're madly working now to digest the 300 plus submissions we've received on our blueprint. I don't know how familiar some of you are with the geography in Ontario, but we held a number of sessions in the summer time just to beat the bushes and get people interested and getting them to read it, and then we went across the province from Cornwall to Kenora with 20 formal sessions in which they could input.

The blueprint covers virtually any of the subjects dealing with hazardous waste, liquid industrial waste management and with municipal refuse, so it's a fairly hefty document and it consists of about a 70 page of, if you will, executive summary and 11 appendices which are in various degrees of development, ranging from quite specific proposals and regulatory frameworks, through to concepts and ideas for which we wanted much feedback before we try to develop them any further.

I wasn't totally kidding in my quick assessment of where we stand on waste stabilization because in our proposals for regulation change etc., we don't deal with the subjects specifically, but they are implicitly covered by some of our other proposals. Basically I think we can summarize our philosophy as saying that we do think that these processes have a very useful role in terms of helping to control contaminant migration, and in that respect they are very much encouraged in Ontario. But our regulations are written, and I'll be talking about some specifically, in a more generic sense. And when I come to the one that may be most applicable to these processes, we will have to recall that they apply to all solid wastes and industrial and hazardous wastes as we generally refer to. So we view it as a tool to control contaminant migration, and we also have proposals in our regulatory strategy to examine solid waste for leachate quality, testing and being able to make predictions on contaminant migration which rolls into another category of waste. One of the first things we did on our blueprint for waste management was change our classification system slightly.

In Ontario up to this point in time, and in fact still prevails today, we really only refer to hazardous waste and municipal waste. You're either in one category or the other. The second category strictly our standard municipal which I think is fairly common around the world in terms of including typical household wastes and commercial refuse, that type of thing. Coming back to site specific waste, we've included this new category and there are a couple of things that must be considered in terms of the definition of a site specific waste in our region. One is that it must be a solid, and we prescribe certain tests to identify a solid, particularly a slump test, and it must be a waste where all we're particularly concerned about is leachate quality and the potential for contaminant migration in the ground water. If it doesn't fit those two, then it's not likely to get into the site specific category as a waste, as it exists at that time. We are proposing to use a leachate test and it's one we really adopted from the Federal EPA in the States and we haven't done your EP3 and the others yet, but just as a basic screening test, we're going to use the EP with some minor modifications that we see suiting our Ontario scene. The objective here would be to subject the solid waste, which might potentially be a site specific waste rather than hazardous, to a leachate

test and if the leachate in our case is greater than 10 times (and I'll talk about this number later) drinking water quality objectives than it has the potential to become a site specific waste. There are two sides to this one. If it's less than 10 we fig re it could go anywhere because we don't figure there should be any landfill site anywhere in Ontario that would have an attenuation factor of less than 10. (That shouldn't be a landfill, even for municipal refuse, if it has.) So we've started with a minimum of 10. We've applied no maximum, but what's required once you have your leachate information is, that in order to be site specific then there must be hydrogeological information, as well as other that says that the site, the proposed receiving site, can attenuate the leachate to basically water quality objectives at the boundary. So if you can't find a site that will do that then your wastes remain as hazardous wastes and would be treated as such in any administrative procedure subsequently. But if they do match up, in other words, if you have the right site conditions with respect to the leachate of that solid waste, then that waste can go into that site, granted you have to take in certain other factors, quantity and location and so on. Generally that would provide for co-disposal of many wastes where all we're concerned of is contaminant migration of ground water.

I do have a few remarks on the leachate test and some of the modifications compared to the EPA, and I think I'll leave that for a later session. And just speaking very generally, we're going to a smaller particle size, where we're grinding and we're defining a procedure more explicitly than at least has been available to us now, in the hope, in both cases, of insuring reproducibility of results of one lab to another, and one sample to another. However, we are similar in many respects in terms of the method of extraction, the pH adjustment, liquid/solid ratios, leaching media, acetic acid and water, and the structural test is the same. So we have a lot of comparability.

Just a word on how I think this will relate to waste stabilization processes. In Ontario, we're not regulating waste stabilization as a science unto itself but we see the process in use as being one that could be beneficial to generators and disposers of waste by being able to move waste from one category to another. In other words, if you apply the process of stabilization

to a waste, then you certainly may be able to move a waste from the category of hazardous waste into a site specific waste, and then the requirements are somewhat different in terms of their management. It can also move certain wastes, like liquid industrial wastes into solid wastes, and therefore sites specific. It can, in summary, condition wastes to provide for co-disposal where the site characteristics are the appropriate match.

I think I can say that in any case even if it dosen't move the waste, say from a hazardous to a sites specific classification, it certainly can contribute to reduced contaminant migration and I think for all of us no matter how we're viewing it, that's essentially our bottom line: how do we stop this material of concern from being mobilized and getting in places where it was not intended. In terms of public involvement, I've mentioned we've been on the road in Ontario with our blueprint for waste management and we, on the industrial side, had three major areas under discussion. We are proposing generator registration for hazardous wastes, we're proposing modifications to our manifest system, and lumped in with that is more generator accountability (taking back refuse loads this type of thing) and we're also proposing the definitions and the classifications that I've just talked about. They could be found in the blueprint, but the actual definition of industrial waste or hazardous waste, which rolls around much of what I've had to say, is found in Appendix 4. It would certainly be very familiar today I think because it's largely adopted from U.S. EPA. I think there's a reason for that. Ontario, unlike Alberta, has very limited funds and the U.S. EPA have done an awful lot of work so we're really not opposed to plagiarizing and giving a little credit; so thank you, David.

As I mentioned, we've been on the road discussing these proposed changes. We propose to bring most of them in as quickly as we can early in 1984 and I must say that from the forums that I attended, there appeared to be very little anxiety about how we were proposing to move with our classifications with the category of sites specific waste. In fact, almost less anxiety than I anticipated originally and I hope that's a good sign and that doesn't mean that they just didn't bother to read the blueprint. There were some suggestions that I think we're going to look at very carefully. One of the suggestions I said I'd come back to, is that in our sites specific category we say if it produces leachate with contaminants 10 times over our drinking water quality objectives

then it may be site specific if you match the site. In other words, if you could prove that the site you're going to take it to has appropriate attenuation abilities. We're going to look at putting a maximum on that, recognizing the vagueness of predicting the hydrogeologic conditions and so on. We will at least look at and I can't predict what the outcome will be. But putting some maximum on that so if it was, for lack of a better number, above 100 times drinking water quality, you may say "No", it can't be handled site specific, you can't talk about co-disposal; we're talking secure landfill, hazardous wastes, that type of thing. We can't give you the bottom line on our proposals because quite honestly we just finished at the end of October on our blueprint trail. We have stacks of submissions. We were up to 300 when I left and they're still coming in by mail and we have staff analyzing and producing matrix presentations for further analysis, to see what people think about such things as perpetual care and for our disposal fees, as well as hazardous wastes, so it will be some time. But I think that generally gives you an outline of where we think we're going.

DISCUSSION

D. Friedman - Two areas: on the site-specific attenuation, how do you evaluate the soil absorption capacity and the dispersion of the ground water, taking into account how much potentially could come out of the waste and use up the soil attenuation capacity.

R. Gotts - Well, that's a tough question and one we're working on, because what we have to do in party with the proposal I outlined is develop just that: the criteria that a proponent would have to follow in analyzing the site. I would think though in many cases he's probably going to limit his look at almost straight dilution in terms of attenuation. In other words, the levels we would allow (of drinking water quality) probably aren't going to be highly substantial, and therefore the main one, may well be the one with dilution.

D. Friedman - Do you anticipate that someone would have to run actual ground water movement and run the dilution?

R. Gotts - There would have to be a full hydrogeologic study and a professional report submitted.

B. Hammond - Have you considered freeze-thaw cycles in your testing protocol?

R. Gotts - No, and I'm glad you raised the question because there's some misunderstanding I think, in many cases, as to what we're proposing versus what isn't in the blueprint and what I haven't talked about. I think if we got into an application to establish a secure landfill where waste stabilization was going to be used as conditioning the waste to deposit there, then through our certificate of approval process we would look at a much broader range of issues, including the type of thing you mentioned. In other words, the applicant, the operator of that site and the operator of that process would have to provide much more information then the fairly simple test we're talking about here, which is merely to put wastes in one classification or another.

P. Cote - Coming back to Dave's question about attenuation. Will the calculations be based on the extraction procedure results.

R. Gotts - Where the extraction procedure results come in is simply a comparison to the hydrogeologic predictions of what you would expect of that waste going in at the boundary of the site.

P. Cote - But that doesn't take into account how much pollutants are available from the waste and over what period of time they will be released. The extraction procedure is a one shot deal. It's one concentration that might or might not be comparable to what's going to happen in the field.

R. Gotts - I don't question that it perhaps doesn't go all the way in that area. I think you're almost asking the same question that somebody said, using the cyanide example this morning and I don't know how far or how long we'll be getting to that level of sophistication in the analysis of solidified waste. I guess my position would be that, assuming that may be a few years away before we know everything we want to know, the type of steps we're taking now improve the climate, if you will, of waste disposal and as we add to it we're only making it better.

THE ALBERTA APPROACH TO HAZARDOUS WASTE MANAGEMENT

Ken Simpson
Waste Management Branch
Pollution Control Division

BACKGROUND

For the past four years, Alberta Environment has been conducting an extensive program designed to address the problem of how to treat and dispose of approximately 100,000 tonnes of industrial and hazardous wastes generated annually in the province. Existing off-site disposal consists mainly of dumping to surface water, sewage systems and landfills whose ability to assimilate or contain chemical wastes is questionable at best.

While no major examples of health or environmental dangers have surfaced to date, growing concern among environment officials and the public at large prompted a full scale investigation of the problem. Early in the program, it was recognized that public acceptance of both the general concept for treatment and the need for special facilities was essential. For this reason a staged process was developed to obtain the necessary expert advice and public views. A Hazardous Waste Management Committee, consisting of prominent outside experts, and Department of Environment officials, was appointed to make recommendations to the Minister of the Environment on the overall approach to hazardous waste management. The Committee's report was released publicly and was itself the subject of an extensive programme of public hearings conducted throughout the province by the Environment Council of Alberta. Their report was published in early 1981. Following completion of the ECA process, the Government appointed the Hazardous Waste Implementation Team to work closely with the Department of Environment to develop a process for the siting of treatment facilities. This Team has now completed its work and the Government has received their report and recommendations. The Team's work has been completed by an extensive series of public information meetings and workshops held throughout the Province.

This extensive process has generated the necessary recommendations for the government to outline the key elements of a comprehensive policy.

BASIC POLICY OBJECTIVE

The basic policy objective for the development of an industrial and hazardous waste management system is to ensure continued human health and environmental quality. Both must be fully protected from adverse effects caused by those waste substances for which the generator or owner has no further use. In order to meet this basic objective, the goal will be to minimize waste production and recycle wastes whenever possible. Where these are not feasible courses of action, the necessary legislative, regulatory, monitoring and infrastructure requirements will be put in place to ensure that all hazardous wastes are treated and disposed in a responsible and controlled manner.

PROGRAM ELEMENTS

The key program elements that will be discussed in this paper include policy decisions, legislation and control, technology, and facility siting.

1. Policy

The Alberta Cabinet in January, 1982 agreed to three major policy decisions. These are that a central treatment facility would be built in Alberta on land owned by the Crown to augment existing and proposed on-site treatment facilities; that the private sector would be encouraged to build and operate the central facility and that a Crown Agency would be formed to oversee the operation of the central treatment facility.

2. Legislation

The Spring 1982 session of the Alberta legislature saw the passage of three bills dealing with hazardous wastes. The Hazardous Chemicals Amendment Act gave legislative control over the disposal of hazardous wastes as well as the requirement for clean up of spills to the Environment. A compulsory manifest system for the tracking of hazardous wastes from "cradle to grave" was also part of the bill. On-site treatment facilities as well as any central off-site treatment facilities would require licencing under the Clean Air and Clean Water Acts.

The Transportation of Dangerous Goods Control Act allowed provincial application of the federal code governing aspects of transportation of all dangerous goods including wastes.

The Special Waste Management Corporation Act formed the crown agency which will have a "watchdog" role over the central treatment facility.

Regulations under the various Acts will set up schedules of controlled wastes and allowed disposal procedures, guidelines for facility approvals under the Clean Air and Clean Water Acts and registries of generators, carriers and disposal facilities.

3. Technology

The question of appropriate technology for comprehensive waste treatment has been the subject of much study and review by Alberta Environment since the beginning of the program. The consensus within the department was that in order to effectively manage the problem, a fully integrated facility would be necessary to deal with wastes generated by companies not having adequate on-site treatment. This would consist of high temperature destruction of organics, physical-chemical treatment of inorganics, chemical fixation and secure landfill for residues and deep well injection for process liquids.

In January, 1982, a Request for Proposals was made to the waste management industry for the construction and operation of a central treatment facility based on the concept of integrated treatment. Nineteen initial submissions were screened down to four by a technical review committee made up of consultants, seconded experts and department officials. The four short listed companies were TRICIL Ltd., Stablex (Canada) Ltd., Chem-Security Ltd., and Genstar-IT Corp. Final selection of a proponent is pending.

4. Facility Siting

It soon became apparent, that the technology, legislation and infrastructure associated with the program were simple matters when compared to finding a site on which to build the facility. Public hysteria fanned by

accounts of the Love Canal, Valley of the Drums and Atlantic City, New Jersey, was sufficient to provoke "Not In My Backyard" (NIMBY) from every corner of Alberta.

Failure to site such facilities elsewhere in North America convinced Alberta Environment to take another look at the standard procedure of selecting a site and then attempting to justify its selection to the local residents. The Alberta approach has been to reverse the procedure - start with the concerns of the public and attempt to incorporate those concerns in the site selection process.

This was done by a series of seminars and workshops held across the province where the format took the form of open discussion and dialogue and where all concerns and fears of the public were fully addressed. These concerns were then consolidated into a series of criteria and constraints that could be applied to any potential site. The criteria that were eventually developed are as follows:

Physical Constraints:
- geology
- hydrogeology
- topography
- surface water

Biological Constraints:
- forestry
- wildlife
- birdlife

Land Use Constraints:
- agriculture
- federal lands
- transportation
- resource extraction

Human Constraints:
- recreation areas
- population centres

Eventually, as part of the siting process, most regions in Alberta will have been subjected to constraint mapping where the above criteria are applied to individual areas to ascertain the location of areas free of constraints. It is a policy of the Department that only such constraint-free areas are considered for siting.

In brief, the siting process takes the following steps:

a. Invitations are received from regional planning commissions, municipalities and interest groups for information meetings and for further discussion on the siting process.
b. Municipality requests that an overview of the area and constraint mapping be done.
c. Presentation of area study to municipality (overlay maps and printed reports).
d. Decision of municipality to look at attracting a hazardous waste facility or not. If yes:
e. Meetings to identify and discuss suitable sites and/or to form citizen committees.
f. Decision of municipality to go ahead with specific site assessment or not. If yes:
g. More meetings and discussions including response to feedback from potential site owners and neighbors to explain programme and exploratory drilling work to be done.
h. Exploratory drilling, evaluation of data from the drilling and presentation of results to municipality.
i. Decision of municipality for further investigation for potential development of facility. This decision would include agreement of the municipality to have a more detailed assessment done (more detailed drilling work, environmental, archaeological, historical and socio-economic evaluation).
j. At any time the ultimate decision regarding placement of waste handling facilities rests with the government.

CONCLUSION

At the present time, it appears that Alberta is well on its way to establishing an integrated treatment facility. The technology, legislation and infrastructure are on schedule and the siting process is well under way in several areas of the province. The true test of the exercise however, will be if and when a community accepts the facility. To date, a number of municipal councils have asked to be considered for the development. Negative public reaction has caused some of these to withdraw their invitations but in at least

three areas, there is strong continuing support for the concept. In fact, there have been plebescites in two towns which overwhelmingly approved the concept of a integrated treatment facility in those communities.

We are confident that our policy of full and open information and involvement of the public in all phases of the program will lead to ultimate success for the lasting benefit of all Albertans.

DISCUSSION

D. Friedman - What type of stabilization/fixation process are you going to be using at this new facility?

K. Simpson - Well, as I said, our proponent elect, as it were, is Chem. Security Ltd. and I do believe they have their own proprietary system for solidification. The actual use of that system vis-a-vis any other particular system is really yet to be determined.

D. Friedman - What type of operational controls will be put on the process to make sure that what comes out on a day to day basis is what should be coming out?

K. Simpson - We're giving that considerable thought at the present time. I think a lot of our program has depended on the choice of basically a fail safe site. We are looking for the type of facility where any migration of contaminants would be controlled through the actual site-specific nature of the site. And the sites we have looked at, I might mention we have picked five sites within the province that are so-called constraint free which we have recommended to the Government for their consideration. Any of these particular sites meet our very stringent requirements of depth of impervious material, lack of ground water facilities, etc. So really the types of controls we put on the proponent and any solidification process certainly have to reflect that long term stability of the site. Basically I think we wouldn't go past the normal requirements of leachate detection and attenuation capabilities of the site. At this point I really can't define that any further.

P. Chaudhuri - Question (Bad audio)

K. Simpson - Because of the water balance on certain of these processes we may be faced with a positive water discharge. Some of the sites in which we have examined, the environmental suitability are quite arid areas and I think the choice of deep well injection was made basically to avoid the idea of a waste stream leaving the plant.

For public reaction, public consumption, we don't want to create a waste river leaving the plant. If we can have very dilute waste waters, only treated waste waters that can be injected we certainly see that as a viable option. I'm not saying it's the only one available but in some of these areas we looked at, we see that as preferable to overloading an existing surface stream.

P. Chaudhuri - Have you not found treatment methods whereby you could actually make it good quality water? Why do you have to inject it in the deep well?

K. Simpson - I guess it's all a matter of economics. Since we haven't come to a final design on the plant there is no way of knowing the actual options that we'll have to take into account. I wonder if John Richardson would mind commenting on some of these things. He's in the audience today.

J. Richardson - As Ken said, we haven't even got to the conceptual design phase in our program and that in turn depends on two things: Firstly, a market survey that will be conducted after regulations have been put in place, or after regulations have been drafted for promulgation. Secondly, the site itself, as Ken says, there are 5 sites that you have put forward to the Ministry for consideration. Each of those sites has different climatic and hydrogeological parameters, so there will be some consideration of those too: what waste streams will be received at the plant, what would result from processing those waste streams by way of wastewater; is it more economic to deep well than it is to treat to the point where it could be drunk? (Which is your point.) But how much money do you spend. It's a combination of technical consideration of the site, problems of the waste stream, volume of the waste stream: And that would be more apparent to us after we've done our conceptual design, which should be after we've gone and done a market survey, which will be after the Government has established for promulgation the regulations as to what is going to characterize as special waste and also what is going to allow to be sent to disposal other than special waste facilities.

T. Bridle - But you are not proposing that you would deep well untreated hazardous wastes, there will always be some form of pretreatment before deep welling. Is that correct?

K. Simpson - That is correct. (Bad audio)

M. Polet - Ken, in your market survey are you going to look at extra provincial wastes and their treatment in this integrating facility?

K. Simpson - Yes. At the present time that's all we've considered for sizing purposes, for the types of material that we will have to treat, you know, that's generated within Alberta. I realize there is always a pressure for interprovincial movement, but basically our terms of reference were to address Alberta waste first.

E. Schmidt - Do you foresee in the future that the Provincial Government regulators may have to pass regulations in the future, determining and insisting that certain wastes will be stabilized before a license is given? Would you foresee that you have to determine this and force people to do this?

K. Simpson - I think, in my comments I mentioned, that the license of the facility is the main control tool. I don't foresee the requirement of solidification unless the owner of a particular facility wishes to accept a particular material that would not be acceptable under untreated conditions, and I'm just conjecturing here, but I think it's really the facility owner that would make that decision whether or not he wished to apply for a license under those conditions where he would have to solidify as part of the license. That's really his choice. I don't see the time when we would require say general solidification of a particular waste.

R. Gotts - I echo that comment. Certainly our regulatory philosophy up to now is aimed at setting out the conditions that we feel protects human health and the environment and leave the method of doing it to the client groups, if you will, who must apply for approval of whatever they propose to do and substantiate their case in that application. So we don't dictate that you must incinerate this or must solidify that. We're saying these are the emissions that are allowed, if any, and you tell us how you propose to do it. And I don't see us changing that philosophy in the near future.

A. van Roodselaar - That leads to the question, would pretreatment, like in Ontario, lead to the possibility of putting this in a non-site specific landfill?

R. Gotts - I'd say "No". Because I think the fact that you're pretreating it echoes part of the definition of controlled waste, of which site specific is one, which is, that it required some special care and handling vis-a-vis the pretreatment and that automatically almost puts you into the position of having to match the landfill to the waste, and therefore site specific category, kind of in total. But when I say site specific, don't be confused. It could be any site that matched, in other words, it may be the one around the corner but as long as your hydrogeologic work matches, if you will, (if you will allow me that liberty for the moment) leachate quality and one can predict with reasonable certainty that the attenuation is there, then that site becomes the site for that site specific waste. It can't go anywhere else until similiar work was done. It's a one to one proposition.

A. van Roodselaar - In the case of Alberta, where you have got a specific site with a specific waste treatment plant how would you handle the situation relative to the Ontario approach?

K. Simpson - Basically the same, I would see that if a particular owner of a particular facility wishes to take a particular waste, he would have to come to us with a proposal, backed up by sufficient testing data, engineering reports or whatever to justify the safety of taking that particular material. Really it's a very simple process. Either the site would justify the acceptance of that waste or it wouldn't. And the fact that more pretreatment is required of that waste, that's just one more possible input into the process.

P. Chadhuri - I wonder if Alberta would consider leachate treatment as a second line of defense, assuming that the contaminant passes the leaching test. But then something goes wrong and your site specific waste becomes a problem waste down the road.

K. Simpson - That's another site specific technology, as it were, to justify the use of a particular site or a particular waste. If the research or the reports or tests show that that's a feasible method whether it be attenuation or whether it be actual collection and recycle or whatever, providing the initial or the philosophical approach is met then it's really a site specific situation that would have to be looked at. But it's certainly one more method that might render a site acceptable as opposed to unacceptable.

J. Defir - I'd just like to perhaps discuss this matter of deep well injection which has been batted around here. In Alberta there are quite a number of secondary recovery schemes, primarily injection of water to maintain pressure in the oil zones. The other area, we have five to six thousand foot formation in the Edmonton, Fort Saskatchewan area which has been used up, to this point in time, for chemical and refinery wastes. Now, what kind of material is discharged into those deep wells? It's everything that cannot be treated on the surface economically. For example, no sewage waste is allowed to be injected into deep well formations anywhere in Alberta. Now, the other area is the heavy oil tar sands operations at Cold Lake. In that area the formations are anywhere from 1,500 to 2,100 feet deep with another one at about 6,000 foot level. Now, the heavy oil projects, up to this point in time, are experimental in nature or have been experimental. They are small. There's no other alternative other than the injection below the production zone of that particular kind of operation at this point in time.

SECTION III

THE RESEARCH ASPECTS

C. Wiles - I'm Carleton Wiles with U.S. EPA's Office of Research and Development Laboratory located in Cincinnati, Ohio. I'm a program manager, which means I know enough about a lot of different things, perhaps in hazardous waste management, to make myself dangerous but not really enough to teach anybody anything. Maybe a few words in clarifying the difference between Dave Friedman's office and mine might be helpful to some of you. Dave is out of the Office of Solid Waste and his staff and his cohorts are involved in the policy type activities and regulatory development activities that we don't really get involved in. We are more of a research organization and the research programs that we do, in a sense, are in response to people like Dave's needs out of the Office of Solid Waste. If you listen closely to some of the things that Dave had to say relative to the U.S. EPA, you could come up with a pretty extensive research agenda on that itself. We're not that large and our resources are not that great, so I think it points out again the need for co-operation among all of us, Canadian Government, U.S. Government, the vendors and the researchers and what have you. We all need to co-operate to get the answers that we feel we need.

I was asked to make a few comments about how we feel or believe stabilization will fit in Solidification Technology and I think Dave has probably mentioned that as have some of the other speakers. I think the relative role of solidification/stabilization technology in the future can become very very important, more so than it is now, as the U.S. regulations proceed. But I think how important that role is, is going to be based upon a number of things and performance definitely is one of them. How well the processes and the processors are going to perform, what kind of reliability the processes and the processors have and the credibility among all of us, and that goes to the regulatory arm also. If we don't come up or the people responsible for the regulations don't come up with meaningful regulations, this is going to cause a big problem. In order to do that I think we need, and I believe that a lot of people would agree, to really know more about the technology. I know that there're probably processors or people that are involved in this thing on a

day to day basis that may not agree with that, but from a regulatory point of view, if we don't understand it, we're not going to be able to develop the proper regulations.

We're going to have three discussions in the research area. First, from Robert Larson and Phil Malone from the Waterways Experimental Station in Vicksburg, Mississippi. WES has been involved in some of the stabilization/solidification technology research for a number of years, primarily dealing with the inorganic side. Then we'll have a discussion from Marty Tittlebaum from LSU dealing with organics and then from Pierre Cote, dealing in some long term stability and with that I'm going to turn it over to Bob Larson from WES. Bob is with the Environmental Laboratory at WES and has more recently, I guess, than Phil been involved in solidification/stabilization and is currently working on a project that we are in the beginning phases of at WES.

A REVIEW OF THE APPLICATION OF SOLIDIFICATION TECHNOLOGY TO INORGANIC WASTES

P. Malone
Waterways Experiment Station

INTRODUCTION

Many industrial wastes are classed as potentially hazardous based upon the high concentrations of toxic metals that can be released to water contacting the wastes. Examples of this type of waste include: electroplating sludges, wastes from metal hardening processes, sludges produced from neutralization of pickling or etching solutions, and wastes from the paint and pigment industries. The major inorganic compounds of concern in these wastes are generally salts or hydroxides of arsenic, cadmium, chromium, lead, mercury, nickel, selenium and zinc.(1) Most inorganic wastes are in the form of wastewater treatment sludges, composed of fine-grained, semi-solid, mixtures of poorly crystalline (or amorphous) metal compounds mixed with materials such as calcium hydroxide or calcium sulfate that are added or produced in the treatment process. Potentially toxic, organic compounds may also be presented in water treatment sludges; these include phenols, cyanides, and chlorinated solvents.(2)

Land disposal or reclamation and reuse are the only useful options in disposal of metal-rich sludges. When a mixed organic and inorganic sludge (such as paint waste) is incinerated to destroy organics, the resulting ash concentrates many potentially toxic metals and may increase the land disposal problem by converting the metal to more reactive or more soluble forms (such as oxides). Typically wastes from incineration must be ultimately disposed of by land burial.

The semi-solid wastes discharged by industrial wastewater treatment processes are often not satisfactory waste forms for land disposal because the material has a high liquid content, is structurally very weak, and may release potentially toxic compounds into the environment through leaching or the production of dust. Ash from incineration systems can be an equally poor performer when containment of potential toxicants is the objective. The goal of solidification (or chemical stabilization and solidification) processes is to produce a solid with better handling and/or containment properties so that the material can be landfilled with little likelihood of adverse effects on the surrounding environment.

This brief review of the application of solidification technology to inorganic waste is intended to point out the past and present use of solidification technology in waste disposal and to indicate some of the basic mechanisms associated with waste containment in solidified products as they are currently being used.

TYPES OF SOLIDIFICATION TECHNOLOGY EMPLOYED

There are five basic strategies that can be followed in attempting to produce a waste form that offers superior containment when landfilled:[3]

(a) Adsorption of wastes onto solids to eliminate free liquid phases and sorb toxic materials onto a solid phase.
(b) Production of new chemical compounds that have low solubility.
(c) Encapsulation of blocks of waste.
(d) Mixing of waste with a thermoplastic matrix to bind the wastes into a monolithic block.
(e) Mixing of the waste with a cementitious binder (such as a portland or pozzolanic cement) to produce a monolithic mass of material.

ABSORPTION

The weakest containment would be developed in absorption. The bonds between many of the potential pollutants (metal ions or organics) and sorbents are weak and toxic materials can sometimes be displaced from sorption sites by competing ions (or compounds) in contacting water. While absorption can take care of the problem of free liquid, it is generally not a system for assuring immobilization of toxic inorganics.[4]

PRODUCTION OF NEW COMPOUNDS

The production of new insoluble, stable compounds is an improvement in containment over sorption in that the chemical bonds formed are stronger than the attraction present in simple sorption.

The goal of altering the chemistry of the waste is to produce compounds that will not react in a mildly-acidic, oxidizing environment that represents

a typical weathering situation on the earth's surface. The normal precipitation reactions used in water treatment systems produce a solid metal hydroxide or sulfide. These precipitates are very fine-grained (95%<200 mesh), amorphous materials that can be broken down or dissolved if exposed to surface conditions. The ideal solution would be to mimic highly-resistant, metal-bearing minerals such as garnet or zircon.

The major problem in developing durable compounds is that each toxic metal has to be considered in developing the system. Metal ions that are widely different in size or charge will no fit into the same rigid, crystalline structures. In most cases, it is not practical to develop one reaction that precipitates all the potentially toxic metals in stable, crystalline compounds. For example, reactions to produce a chromium garnet from electroplating wastes have been explored;[5,6] but this crystalline silicate will not incorporate any appreciable amounts of other toxic metals in its lattice structure. Treating a mixed metal hydroxide waste would require several different reactions that yield a variety of compounds.

ENCAPSULATION OF WASTE BLOCKS

Waste encapsulation techniques involve the use of an inert barrier layer between the waste and the surrounding environment. One successful adaptation of the barrier technique with blocks of waste involves fusing a 0.5-cm-thick jacket of polymer material (polyethylene) on the outside of a monolithic block of wastes. Unless or until the polyethylene jacket fails there is no contact between the waste and surrounding environment. No major loss of the waste to the environment would be expected unless the monolithic mass inside the jacket breaks down.[7,8]

BLENDING WITH THERMOPLASTIC MATERIAL

Another, smaller-scale approach to a barrier system involves incorporating the particulate wastes into a hydrophobic, thermoplastic matrix, such as asphalt.[9] The waste are dried and blended with a hot, thermoplastic medium that hardens on cooling to produce a solid mass. The wastes can be further protected by coating the outside of the waste/matrix mass with a layer of pure thermoplastic. While this micro-scale encapsulation may not be suitable for

all inorganic wastes (oxidizers and other compounds that react with the thermoplastic material cannot be handled); the technique has been successfully employed with selected metal hydroxide sludges.[10]

ADMIXING SYSTEMS

Admixing inorganic wastes with cementing binders such as portland cement, pozzolanic cement, or organic polymers has been widely used to produce waste forms for disposal. Selected accelerating agents and absorbers have been employed with binders to prevent delay of setting reactions and improve waste containment. The major difficulties encountered with this type of waste solidification relate to materials in a waste that prevent the binder from setting. If the binding material does not set then the particulate waste will have a much larger area for pollutant transfer and fine-grained material may be washed away or dispersed as dust. The action of the binder is critical to the containment performance of the waste mass.

Organic polymer binders are generally the most easily disrupted binding systems. For example, some urea-formaldehyde polymers require a very acid waste (approximately pH = 2.8) to initiate polymerization.[1] Most metal hydroxide wastes are highly alkaline and neutralize acid added to cause polymer formation. Other binders like acrylates require the use of reducing and oxidizing agents as initiators and accelerators. Most metal hydroxide wastes with iron or chromium present will react with a strong oxidizer or reducer. Systems using organic polymer binders have to be used with great care.

Inorganic binding reactions involve primarily silicates and aluminates in portland or pozzolanic cements. While numerous retarding and interfering compounds are known, the systems are alkaline and with additives and absorbents the cementing reactions can be made to take place. The new crystalline phases and gels forming in silicate cements have some capacity for precipitating or capturing metal ions in solution during the hydration reactions,[11,12,13,14] but the capacity is relatively limited and most metal compounds in wastes are simply embedded in a concrete matrix.[2] The concrete matrix isolates the waste particles and maintains an alkaline condition that slows the solution of embedded metal hydroxides.

SUMMARY

Useful systems for immobilizing inorganic wastes are available. While each system has limitations with regard to the waste compounds that can be handled and the costs, the basic technology is useful and can produce a more chemically stable and leach-resistant product than the fine-grained sludges usually placed in landfills. There are still many unanswered questions with regard to solidification systems and the actual mechanisms for preventing waste loss. As interest in these materials increases, more attention may be paid to discovering how waste forms can retain toxic material and how this retention can be improved.

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DISCUSSION

D. Friedman - Do you have any data on silicate based processes similar that you have cement and pozzolanic based processes.

P. Malone - Well, we didn't really take any of the soluble sodium silicate processes and go through the same operation. We probably should do that in the future. That would be a good item, I would say, in that we probably see silica gel forming in those processes very early and the major mechanism may well be that the gel absorbing the metals.

V. Douglas - I'm interested in your asphalt base and encapsulation. Have you looked at the organics that may be leached out of the asphalt?

P. Malone - In fact, the asphalt is used as a liner in potable water storage. This problem doesn't exist as far as the asphalt is concerned if the organics are in the waste there is a possibility that the organics will get out.

V. Douglas - As far as asphalt in potable water use, that is a current interest of the Department of Health, because of the potential leaching of polynulcear hydrocarbons.

John Defir - You eluded several times to fly ash being used as a media for the solidification phase or was it a disposal item? Because in Alberta, the interest is in power plants which are being fueled by coal, and there at the mines you see, what we're doing right at this point in time is, the fly ash is either ponded or distributed throughout the mined out area. I was very interested in your presentation from a point of view, "What is fly ash used for", is it a disposable item or a medium.

P. Malone - Some of the gentlemen here from Envirosafe will go into this in much more detail.

APPLICABILITY OF SOLIDIFICATION TO ORGANIC WASTES

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Solidification/stabilization is a widely practiced economical means of preparing inorganic toxic wastes for landfill disposal. Similar technology is practiced for mixed organic-inorganic waste streams, but there is little information about whether the organic compounds are effectively immobilized by any chemical or physical interaction or whether the organics affect the nature of the solidification medium.

Within the context of this research effort, a distinction is made between the terms "solidification" and "stabilization". Solidification is defined as a process of adding solid (matrix) material or materials in sufficient quantities to the waste so that it can be handled as a particulate solid. Stabilization refers to the process whereby a binding agent makes hazardous wastes immobile, either by physical or chemical interactions. Present stabilization and solidification techniques generally include cement based, self-cementing, lime-based or pozzolanic techniques, thermoplastic, thermosetting organic polymer, macroencapsulation, and glasses and ceramics techniques.

During the first year of the project, an assessment of the technical feasibility of stabilization/solidification of hazardous organic liquid wastes was investigated. The objectives of this phase are listed below.

1. Determine the present state-of-the-art of stabilization of hazardous organic liquid wastes and sludges.
2. Identify the principal types and estimated quantities of hazardous organic liquid wastes and sludges.
3. Identify potential physical, chemical, and cementitious binding mechanics between organic wastes and candidate stabilization materials.
4. Identify mechanisms that interfere with stabilization processes.
5. Identify pretreatment techniques to enhance the stabilization of organic wastes.
6. Develop a suggested research program to evaluate the performance of selected stabilization techniques.

In the research planning phase, a thorough review of available literature was conducted. Information sources reviewed or contacted were:

Literature

135 technical papers, reports, brochures and pieces of correspondence

Personal Contacts (representative)

Government Agencies

Alberta Environmental Centre
U.S. Environmental Protection Agency
Waterways Experiment Station, U.S. Army Corps of Engineers
Environment Canada

Industry

Chemical Manufacturers Association
Union Carbide Corporation
Dow Chemical Corporation

Academic/Research Institutions

New York University
IIT Research Institute
Southwest Research Institute
Radian Corporation

Waste Stabilization Companies

Chemfix Technologies, Inc.
Stablex, Inc.
Soil Recovery Systems, Inc.
Environmental Protection Polymers, Inc.

It was established from the literature and other information collected that the special characteristics and problems associated with the stabilization/solidification of hazardous wastes have not been adequately addressed.

It was also established that before any significant progress could be made in the development of techniques for the long-term stabilization of organic hazardous wastes, fundamental research on bonding and interfering mechanisms associated with such processes must be accomplished. Development of predictive methods of behaviour of the wastes would allow for the rational selection of binder and matrix materials to ensure the short and long-term satisfactory

performance of the stabilized waste.

With this in mind, a specific research program was developed entitled, "Identification of Bonding and Interfering Mechanisms Associated with Stabilized/Solidified Hazardous Organic Wastes". An objective of this project is identification of potential physical, chemical, and cementitious bonding mechanisms between organic wastes and candidate stabilization materials. Fulfillment of this project objective will lead to another stated objective, namely identification of mechanisms that interfere with stabilization processes and identification of pretreatment techniques to enhance the stabilization of organic wastes.

The scientific questions to be considered in the present investigation are:

1. Is the process mainly one of physical entrapment or do some chemical binding forces exist between organic and matrix?
2. What chemical transformations do the organics undergo during solidification/stabilization?
3. Are the interactions concentration- and/or time-dependent?
4. How is the integrity of the cement matrix affected by the presence of the organic?

The binding between an organic and cement can range from none at all to strong, irreversibly formed covalent or ionic bonds. Cement is basically calcium silicate, and the main interactions to be expected with organics would be hydrogen bonding and the possibility of formation of covalent Si-O-C linkages (Figure 1). The solidifying cement medium is highly basic, and some reaction chemistry could be expected with a number of classes of organics, as illustrated in Figure 2.

The research approach is summarized as follows:

1. Solidify some pure organic compounds using Portland cement
   a. Pentachlorophenol
   b. Hexachloro-1, 3-butadiene
   c. Butyl Phthalate
   d. Ethylene Glycol

2. Vary the proportion of organic to cement
3. Vary the time of set
4. Extract the sample with solvents of varying polarity
5. Examine the sample microscopically

Several pure organics, including two water-soluble compounds, are solidified with cement using various weight rations or organic to cement. After curing, the samples are ground and extracted with solvents of varying polarity; dichloromethane, dimethyl sulfoxide and water. The purpose of the extraction is twofold: (1) to get back as much of the organic and its reaction products as possible in order to characterize any reaction chemistry occurring during solidification, and (2) to get qualitative data about the nature of the binding of the organic to the cement from the conditions of extraction required to recover the organic. Both before and after extraction, scanning electron microscopy is used to characterize the cement matrix.

As the weight ratio of organic to cement varies from 50:1 to 1:1, the product of solidification varies from a solid indistinguishable by the naked eye from hardened cement to a two-phase system with hardened material and supernatent liquid (shown in one case to be the pure organic). Initial extractions have been performed on samples prepared using 1-decanol, a water-insoluble hydrocarbon-like organic, and ethylene glycol, a water-soluble polar organic. Table 1 contains extraction data on a sample of one part (by weight) decanol to ten parts cement and four parts water. The samples are hardened blocks which require grinding down before extraction. The results shown are for extraction with dichloromethane, a nonpolar organic solvent. These results indicate that the percent recovery is reasonably reproducible from sample to sample, and also indicate that there is little binding of decanol to the cement, since the percent recovery is large. Repeated extraction of the same sample results in overall recovery of ninety-seven percent of the decanol (Table 2). The remaining three percent may be physically (or chemically) trapped in pores in the cement matrix. Table 3 shows the effect of a variable amount of grinding on the percent recovery of decanol in a single extraction with dichloromethane. The finer the particles before extraction, the greater the recovery. A reasonable interpretation of this finding is that physical entrapment is at least one mechanism of binding of the organic.

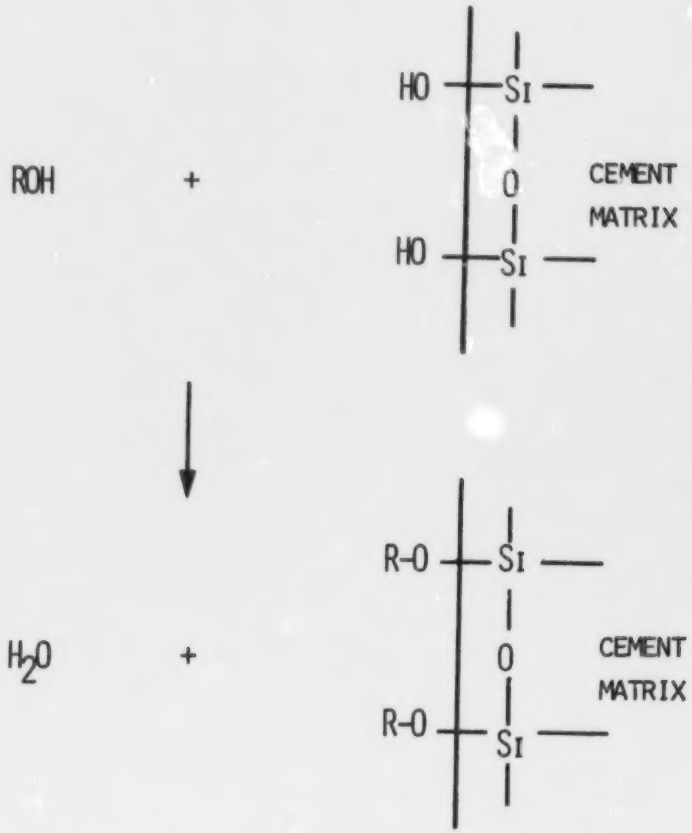


FIGURE 1. SURFACE INTERACTION OF ORGANICS RESULTING IN COVALENT BONDS.

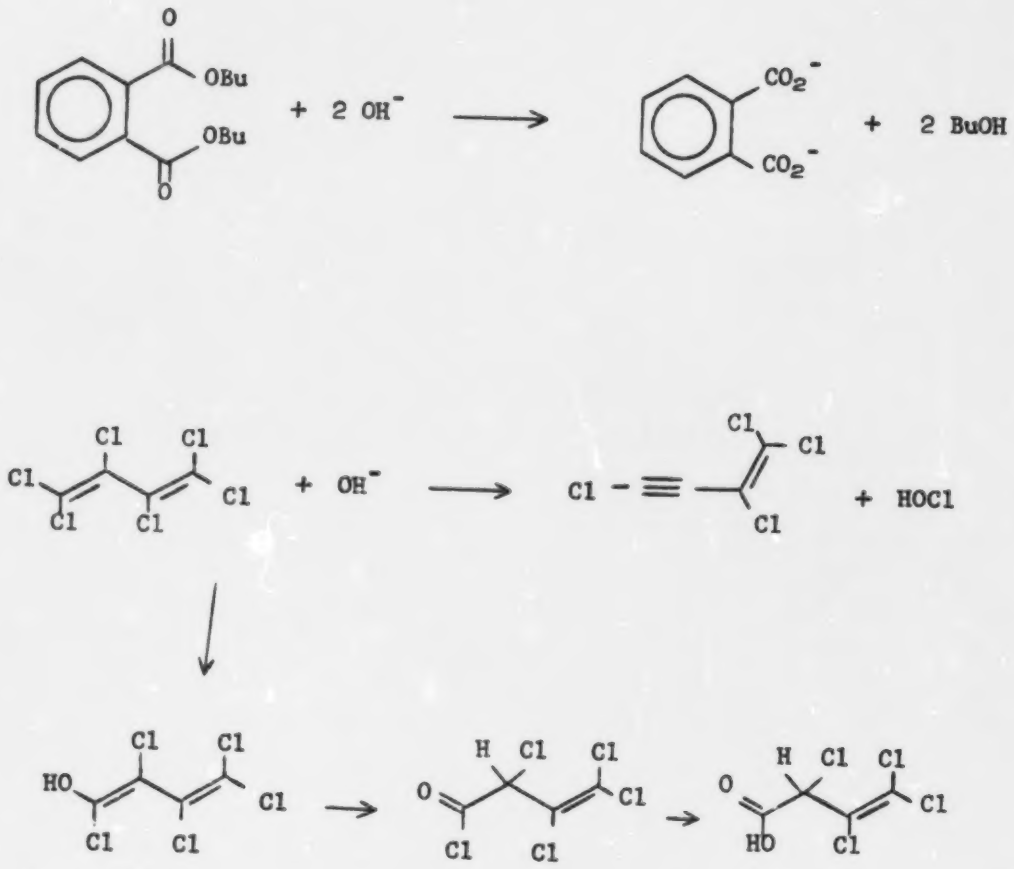


FIGURE 2. TYPICAL REACTION CHEMISTRY OF SELECTED ORGANIC WASTE CONSTITUENTS UNDER BASIC CONDITIONS

Table 1. Recovery of 1-Decanol from Cement as a Function of Volume of Dichloromethane (DCM) used for Extraction

Volume of DCM	Percent Recovery of 1-Decanol			
	Run 1	Run 2	Run 3	Average
60 ml	86.8	85.8		86.3
120 ml	89.0	88.8	89.0	88.9
180 ml	89.2	91.1	92.5	90.9

Table 2. Multiple Extractions of Decanol/Cement* with CH_2CL_2

Extraction	Percent Recovery			
	Run 1	Run 2	Run 3	Average
1	89.8	89.6	89.9	89.8
2	6.8	6.7	6.8	6.8
3	0	0	0	0
Total Recovery = 96.6 Percent				

*1.0 g decanol + 10.0 g cement + 4.0 ml H_2O

Table 3. Recovery of 1-Decanol from Cement as a Function of Particle Size*

	Percent Recovery of 1-Decanol			
	Run 1	Run 2	Run 3	Average
No Screening (60 mesh)	77.9	80.5	80.1	79.5
60 mesh	83.3	84.6	88.0	85.3
100 mesh	86.8	85.8		86.3

*Each run was the result of an extraction with 60 ml of dichloromethane on a sample made from 1.0 g decanol, 10.0 g Portland cement and 4.0 ml water. The sample was extracted 48 hours after preparation.

The first extensive set of extractions of samples containing varying ratios of organic to cement have been performed on samples prepared with ethylene glycol, a water-soluble organic which will be in intimate contact with the cement during the setting. Ethylene glycol is substantially soluble in all of the solvents used in the extractions, but the percent recovery reflects the expectation that the interactions of ethylene glycol with water will be greater than those with dimethyl sulfoxide and dichloromethane. As is typical of solvent, extractions which can be characterized by a single extraction coefficient, the percent recovery of ethylene glycol is approximately the same with varying content of organic in the samples. The behaviour is seen for dichloromethane and water as solvents. The results with dimethyl sulfoxide, however, illustrate the additional information which can be obtained using solvents of varying polarity rather than just water extraction. A break in the percent recovery occurs between low loadings of organic and high loadings of organic. Two reasonable interpretations of that fact are: (1) there is a chemical binding between ethylene glycol and cement and the active binding sites are being saturated above the break point, or (2) above the break point the organic has caused the cement matrix to be quite different and less capable of containing the organic. It is deviation in behaviour such as that illustrated here which will be monitored in our future extraction studies.

As previously stated, one purpose of the present study is to characterize the mechanisms of organic liquid waste stabilization/solidification. Conceptually, there are two possible mechanisms. These may be termed "physical entrapment" and "chemical interaction". The terminology and processes themselves are related to the two basic types of adsorption which can be quantified in terms of heat of adsorption, (for which $\Delta H_{ad} < \sim 15$ kcal/mol), then it is known as physisorption. When $\Delta H_{ad} > \sim 15$ kcal/mol, and therefore the bond is stronger and more chemical-like, then the adsorption process is termed chemisorption.

A careful examination of the several chemical analyses performed during the first six months of the present research phase suggests the operation of both of these antipodal solidification mechanisms. First, experiments have already been discussed wherein solidified waste samples were ground to a predetermined particle size and extracted by chemical means. After this extraction, the amount of organic waste recovered was always less than the original amount. However, when the same sample was ground further and the extraction process repeated, more organic was recovered (Table 3). One might imagine the extrapolation of this procedure until the entire volume of organic was recovered.

Such behavior clearly suggests that the organic is mechanically, or using another term, physically bound to the cement; perhaps inside the small cavities which are opened by grinding. This behavior is illustrated in Figure 3. In this figure, a cement particle is schematically represented by an inorganic mass of irregular shape from 50 to 500 nanometres in extent. This could be the mean diameter, for example, of a small pore containing liquid organic waste. Note that the interface between the solid and liquid is shown to be distinct since no, or little, interaction has occurred between the two.

The dimethyl sulfoxide extractions suggest that there may be some occurrence of chemical interaction. This is evidenced by the marked breakpoint in the percent recovery of organic waste from the ground samples. The nature of this interaction might involve the formation of a diffuse interface between the liquid waste and solid inorganic particles; its exact nature is important to the complete understanding of the stabilization process, and its characterization is

one of the primary goals of the present research project. A schematic representation of the chemical interaction mechanism of waste stabilization is shown in Figure 4.

Figure 5 summarizes the important mechanistic observations derived from the initial chemical extraction and grinding experiments. These findings suggest that both physical entrapment and chemical interaction are likely to be operative in the ethylene glycol/cement system. The degree to which each is involved, however, cannot be inferred from the chemical extractions alone, nor can the active sites be identified.

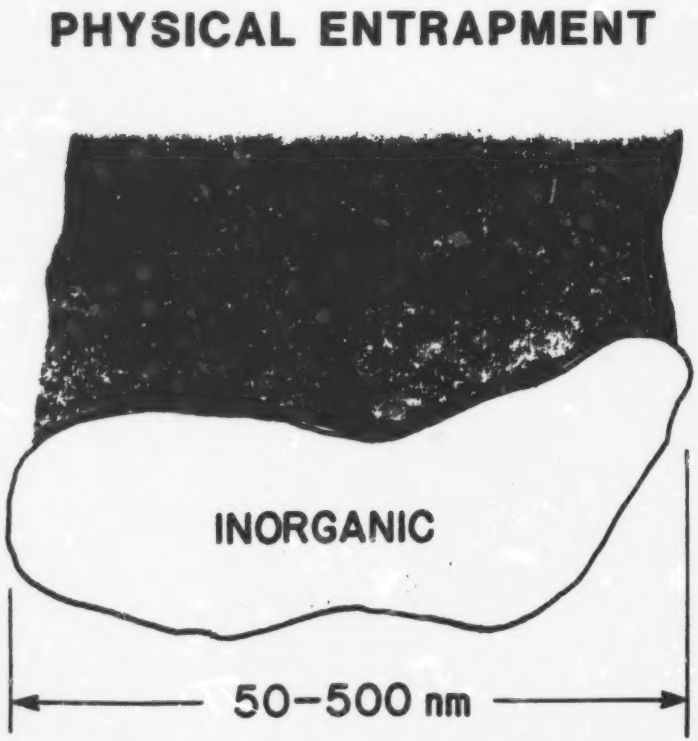


FIGURE 3. A SCHEMATIC DIAGRAM ILLUSTRATING PHYSICAL ENTRAPMENT.

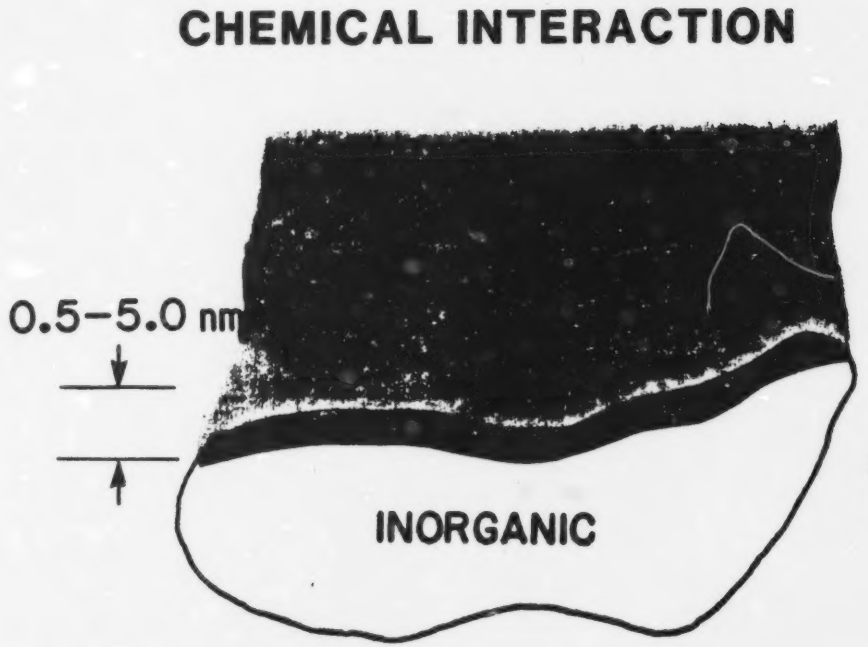


FIGURE 4. A SCHEMATIC DIAGRAM ILLUSTRATING CHEMICAL INTERACTION.

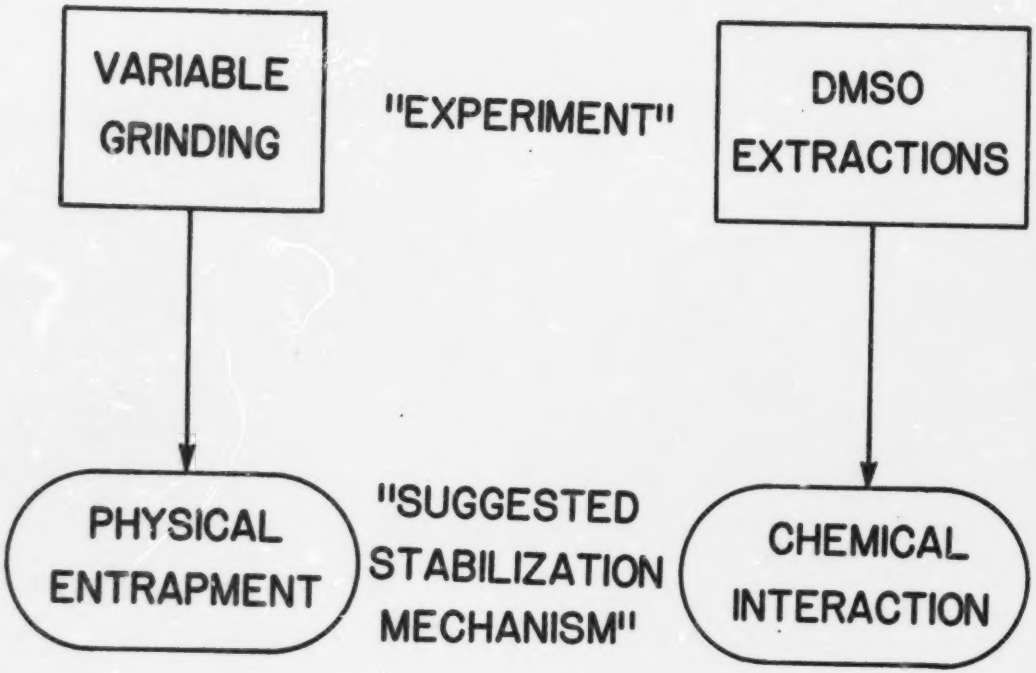


FIGURE 5. PRELIMINARY CONCLUSIONS FROM INITIAL CHEMICAL EXTRACTIONS

This factor leads to the use of microscopic analysis in the study. These experiments are performed on an ISI-60A Scanning Electron Microscope (SEM) which is equipped with an Energy Dispersive X-Ray Analyzer (EDX). The instrument is shown in Figure 6. Specimens are prepared for observation in three ways; each reveals the internal structure of the stabilized waste system. In the first method, the specimens are removed from the glass specimen bottles in which they are cured. Both longitudinal and transverse cross-sections are then cut from the specimen cylinders using a diamond wafering saw. The second method of specimen preparation consists of fracturing the specimen (Figure 7). The fracturing process is performed at liquid nitrogen temperature in order to assure a brittle failure and therefore to limit the degree of distortion due to preparative technique. Specimens are also prepared by simply preserving the smooth surface formed when the waste/cement system cured against the inside surface of the glass bottle. In each case, the specimens are mounted, using silver conductive cement, onto one inch diameter aluminum stubs which fit into the SEM. Finally, each specimen is coated with gold/palladium in an argon ion sputter coater.

The results of the microscopic analyses are shown in Figures 8 through 11. Figure 8a is a micrograph of a control sample. In the control experiment, cement mixtures are prepared without the addition of the organic waste. The surface adjacent to the container glass is examined. Figure 8b is the cement/waste sample in which the waste is ethylene glycol. The magnification in each case is 300X and there are two distinctly different regions on the sample surfaces which can be identified. The smooth, nearly featureless areas correspond to very densely packed cement, while the other regions are pore-like and correspond to cavities within the matrix. This indicates that the pore density in the sample containing the organic waste is much less than in the control sample. Figures 9a and 9b are 800X magnifications of the region interior to one of the pores shown in Figure 8. The morphology of some of the small structures is obviously different. In particular, the micrograph of Figure 9a shows several small, needle-like crystals which were not observed in the control specimen shown in Figure 8a. Although the chemistry of the crystals is not known at this time, it can be concluded that they were formed due to either the different chemistry of the sample containing the organic waste or because of different environmental, including thermal, during the crystallization. In either case, it indicates that the structure of the pure cement is different from that of the cement containing the waste.

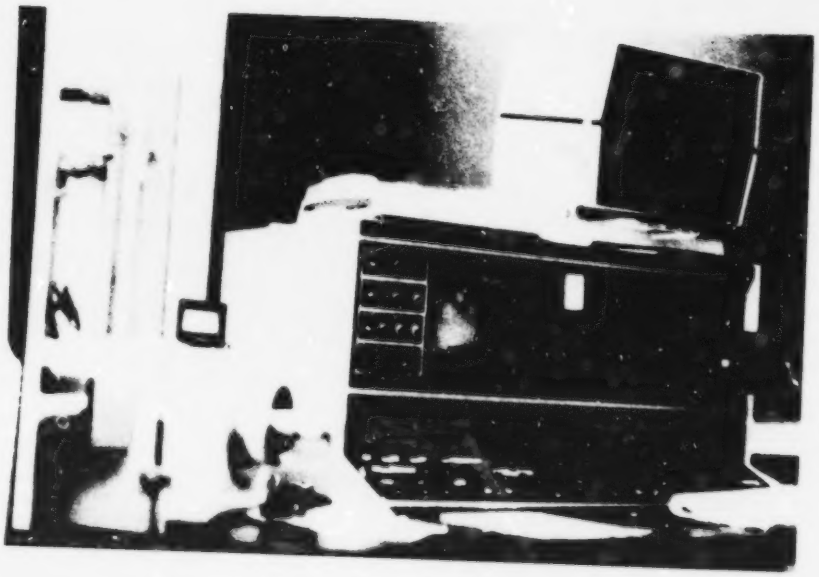
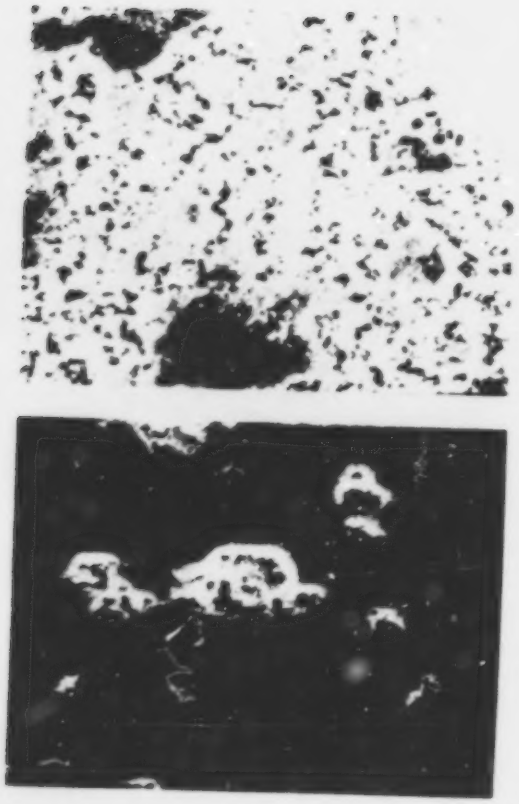


FIGURE 6. AN ISI-60A SCANNING ELECTRON MICROSCOPE EQUIPPED WITH AN EDAX ECON-2 ENERGY DISPERSIVE X-RAY ANALYZER.

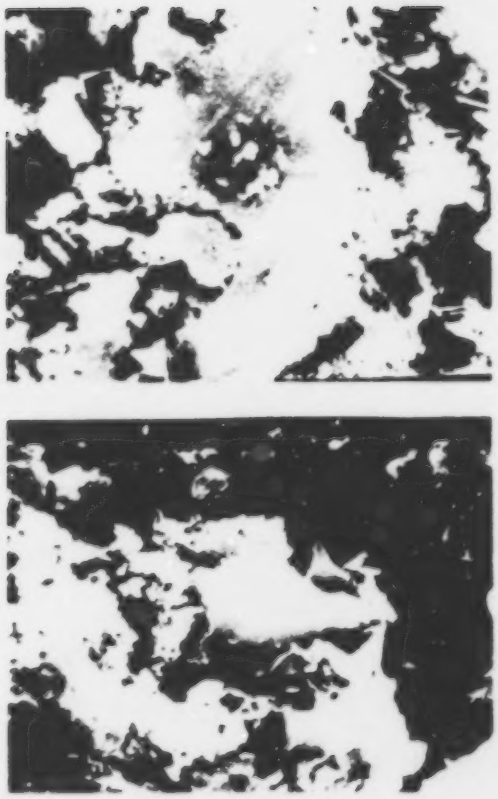
FIGURE 7. A FRACTURED CEMENT/WASTE SAMPLE



(a)

(b)

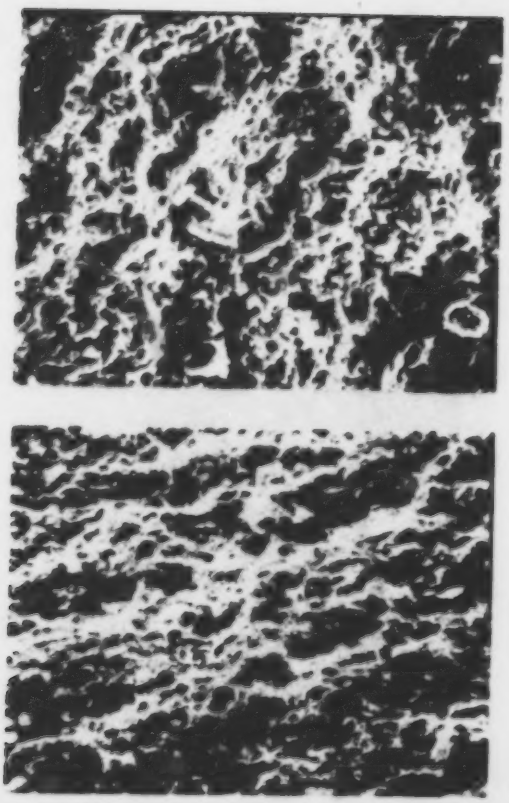
FIGURE 8. SEM MICROGRAPHS OF THE (a) CONTROL (PURE CEMENT) AND (b) WASTE CONTAINING SPECIMENS. (MAGNIFICATION: 300X)



(a)

(b)

FIGURE 9. SEM MICROGRAPHS OF THE (a) CONTROL, AND (b) WASTE CONTAINING SPECIMENS. NOTE THE SMALL NEEDLE-LIKE CRYOTALLITES IN (a). (MAGNIFICATION: 3500x)



(a)

(b)

FIGURE 10. SEM MICROGRAPHS OF THE (a) CONTROL, AND (b) WASTE CONTAINING SPECIMENS. (MAGNIFICATION: 200x)

FIGURE 11. AN SEM MICROGRAPH (AT 1500x MAGNIFICATION) OF A FRACTURE SURFACE IN A WASTE CONTAINING SAMPLE.

Very interesting results were observed from the fracture specimens. The micrographs of Figures 10 and 11 illustrate this. Figures 10a and 10b are 200X magnifications of the fracture surfaces of the control and the waste containing samples, respectively. The fracture surface clearly shows that although the fractures occurred at liquid nitrogen temperatures, the complex material failed in a ductile mode. This should be compared to the fracture surface of Figure 11 which is of the waste containing sample. In this micrograph, the crystallites making up the cement/waste mixture have failed brittly as evidenced by the straight brittle cleavage lines on the surface of the crystals. The change in fracture behavior upon the addition of the organic waste implies that there has been a change in the elastic properties of the crystallites which make up the system. Such changes in elastic properties can in turn be related to changes in the chemistry of the crystallites.

In summary, the use of electron microscopy has yielded valuable information about the structure and formation of solidified liquid waste systems. The results suggest that there may be chemical interaction between the organic liquid and the inorganic solids. Further electron microscopy is proposed. The research will attempt to answer two very important questions:

1. Is the mechanism of stabilization primarily one of physical entrapment, one of primarily chemical interaction, or one which is a combination of both mechanisms?
2. Where are the trapping sites located in the waste/cement complex?

The reasons for requiring an answer to the first question is perhaps obvious from the preceding narrative. However, it may be that the reasons for the second question require some explanation. Actually the information gained from a knowledge of the trapping sites is intimately related to the ability of an environmental engineering being able to predict whether or not a given waste/stabilizer system will maintain its waste containing properties over extended periods of time or whether it will even work at all. Therefore, answers to the second questions are vitally important. To this end, a novel experimental protocol has been developed and is illustrated in Fig. 12. It is planned to continue the chemical extraction experiments and the electron microscopy on similar systems, but to include a specially formulated organic liquid which when added to the cement and cured will be chemically detectable

using EDX. This will allow chemical analysis of extremely small surface areas, for example the surface associated with the inside of a single pore within the cement. Then the presence of the organic waste can be positively verified. Additionally, by analyzing the chemistry of a single pore or particle, argon ion sputtering away the surface of the particle, and then re-analyzing the surface chemistry, one can determine the depth to which chemical interactions might have occurred. From these measurements, a depth profile similar to the one illustrated in Figure 13 can be obtained.

The key to the experiments described is the ability to do micro-chemical analyses from regions in the waste/binder complex the morphology of which has been characterized microscopically. Unfortunately, the EDX spectrometer is not sensitive to the light elements contained in the common organic wastes. Therefore, it is proposed that an organic be tagged with a heavy atom that can be detected by the instrument. Since phenols are important organic wastes and since it is relatively simple to chemically add a simple side group which contains a heavy atom, para-trimethylgermylophenol will by synthesized in the laboratory and then bound to Portland cement in the manner previously described. It is anticipated that the interaction between the tagged organic and the cement will be similar to the interaction between the cement and the untagged organic.

It is hoped that through the series of experiments outlined in the preceding paragraphs, the precise mechanisms of waste stabilization can be established.

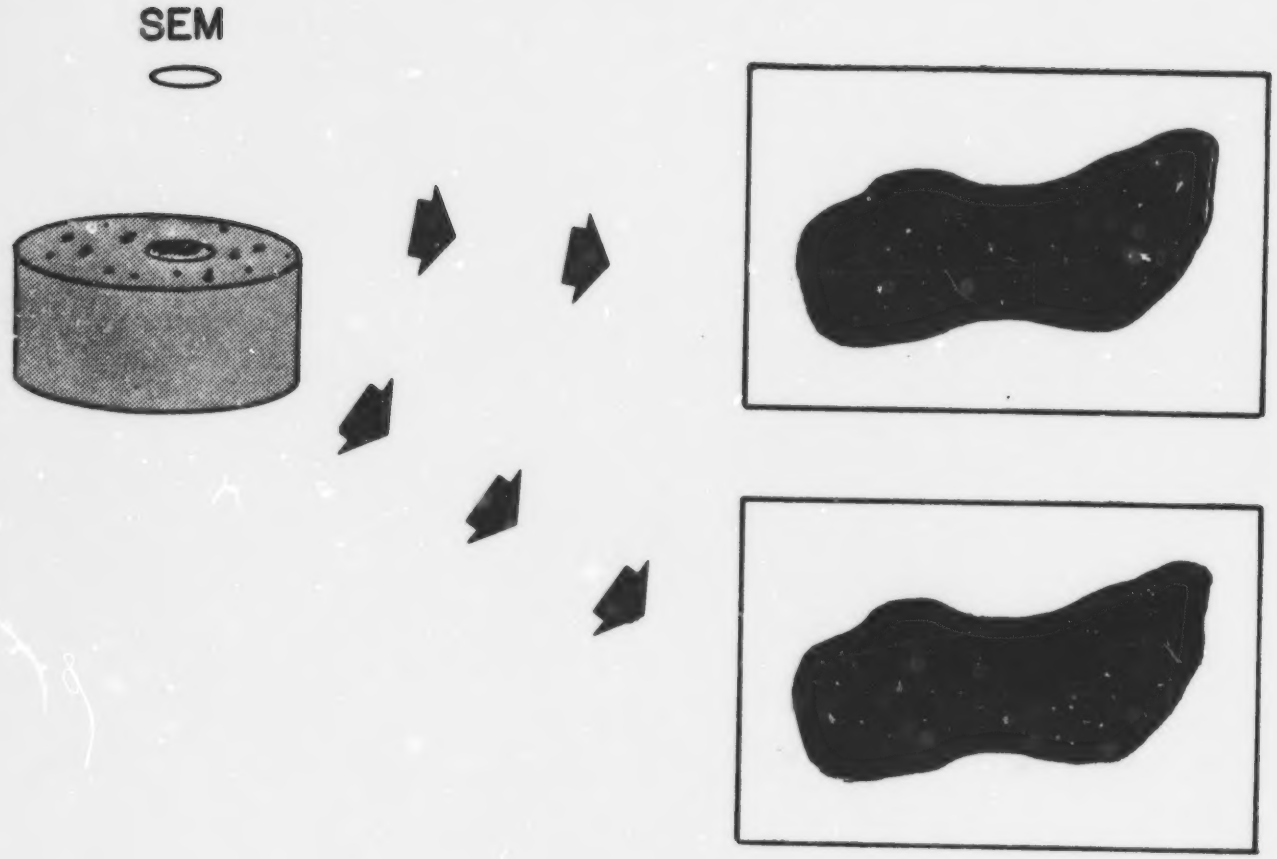


FIGURE 12. A DIAGRAM ILLUSTRATING THE PROPOSED TAGGING EXPERIMENTS.

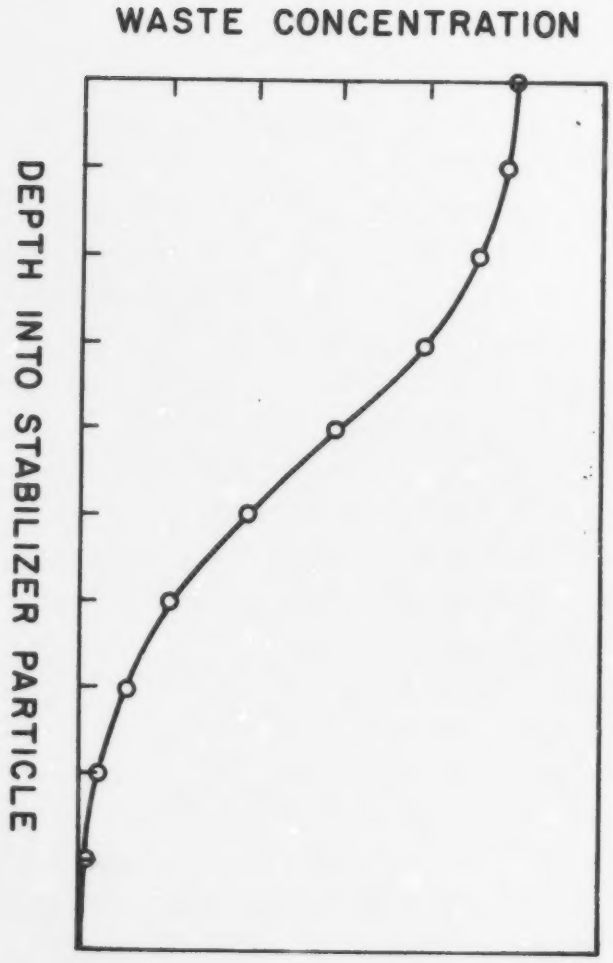


FIGURE 13. A DEPTH PROFILE SIMILAR TO WHAT CAN BE DETERMINED FROM THE PROPOSED TAGGING EXPERIMENTS.

DISCUSSION

P. Chaudhuri - I wonder what's your rationale for undertaking this research project, particularly when there are established methods, effective methods for dealing with organic waste, namely by incineration or biological treatment.

M. Tittlebuam - Well, I tell you what our original thinking was in Louisiana and that's where we're most familiar with. The solidification or stabilization or fixation, whatever you want to call it, of organic wastes or mixtures of organic waste is almost exclusively what is done, and this is disposed of, and I'll use the term loosely, in secure landfills where the water table varies from 0 to 10 feet and we are having some very, very serious problems and we're also having some very serious problems in producing scientific data to backup our concerns. So to start with, that was the rationale, not whether there are obviously better techniques of handling organic wastes. It comes right down to what's actually taking place, specifically in our part of the country. And we talked about this last Thursday a little bit in Cincinnati: they use very basic techniques and that was our concern and the basis for our starting in this direction.

P. Cote - I would like to add something to the answer that you gave, that organic waste can always be present in a small fraction in inorganic matrix. That would be solidified. I guess it's interesting to know what would happen in terms of containment to those organics.

M. Tittlebuam - There's a tremendous number and quantity of organic wastes and at the present time there seems to be very little incineration that is taking place, and even with that, the end products of the incineration, the fly and the bottom ashes are still going, for the most part, to landfills. So we think it's a problem that needs to be addressed at the basic level, so we can then address it at the pragmatic level at some time in the future.

EVALUATION OF THE LONG TERM STABILITY OF SOLIDIFIED WASTES

P. Cote
Environment Canada
Wastewater Technology Centre

TABLE OF CONTENTS

		Page
1	INTRODUCTION	84
2	LEACHING DRIVING FORCES	84
3	EXPRESSION OF LEACHABILITY	88
4	FACTORS AFFECTING LEACH RATES	89
4.1	Temperature	90
4.2	Waste Form	90
4.3	Leachant Composition	90
4.4	Flow Conditions	91
5	LONG TERM LEACHABILITY INFERENCE	95
5.1	Accelerated Testing	96
5.2	Modeling	97
6	FACTORS TO BE CONSIDERED IN THE GENERATION OF LABORATORY LEACHING DATA	106
	REFERENCES	108
	LIST OF SYMBOLS	112

1. INTRODUCTION

Hazardous wastes are solidified prior to land disposal in order to reduce the potential for groundwater contamination. Solidification consists of creating a waste form made up of a skeletal structure of insoluble substances, with the pores impregnated with the waste. Upon contact with percolating rain water or the surrounding groundwater, contaminants will be transferred from the waste form to the liquid phase. The rate at which this phenomenon takes place, the leach rate, is the source term for a hydrogeological evaluation of the waste disposal site. The magnitude of the leach rate and site specific considerations of attenuation and dilution are necessary to assess the environmental impact of the waste disposal practice. The discussion in this paper is limited to evaluation of leach rates.

Leach rate measurement of waste forms cannot be performed over the lifetime of a disposal site. Therefore, inference methods, based on data collected over relatively short periods of time, must be relied upon to assess the long term stability of the waste forms. These methods include laboratory testing under environmental conditions that accelerate the leaching process and predictive mathematical modeling.

A large number of laboratory methods have been used for conducting leaching tests. Compilations were published by Mendel (1973) and Lowenbach (1978). Description and analysis of the different testing conditions that affect leachability results have been presented by Stone (1981), Mendel et al (1981) and Barkatt et al (1981). In this paper, the leaching process is first described in terms of basic thermodynamics, chemical kinetics and mass transport principles. Based on that background information, methods of accelerating the leaching process are proposed and simple predictive mathematical models are reviewed. Finally, considerations for the design of laboratory leaching tests compatible with the intended uses of acceleration or mathematical model calibration are discussed.

2. LEACHING DRIVING FORCES

A fundamental approach to leaching based on thermodynamics was presented by Machiels and Pescatore (1982a). The overall equilibrium state of a

multicomponent, heterogeneous closed system consisting of ζ phases and s species is given by:

$$\begin{aligned}
T^{(1)} &= T^{(2)} = \ldots\ldots T^{(\zeta)} \\
P^{(1)} &= P^{(2)} = \ldots\ldots P^{(\zeta)} \\
\phi^{(1)} &= \phi^{(2)} = \ldots\ldots \phi^{(\zeta)} \\
\mu_1^{(1)} &= \mu_1^{(2)} = \ldots\ldots \mu_1^{(\zeta)} \\
\mu_2^{(1)} &= \mu_2^{(2)} = \mu_2^{(\zeta)} \\
&\vdots \\
\mu_s^{(1)} &= \mu_s^{(2)} = \ldots\ldots \mu_s^{(\zeta)}
\end{aligned} \tag{1}$$

where the superscript denotes the phase and the subscript the species. T and P represent the temperature and pressure, respectively. ϕ represents any relevant scalar potential (e.g., redox). μ denotes the chemical potential which can be expressed:

$$\mu_i = \mu_{i,o} + RT \ln a_i \tag{2a}$$

where $\mu_{i,o}$ = chemical potential at some arbitrary reference state, called the standard state

R = gas law constant

a_i = activity of species "i"

For a solute in aqueous solution, it is convenient to refer to a hypothetical standard state in which the molality is unity, at unit pressure. Under those conditions, the activity of a species can be represented by its molal concentration, provided it is sufficiently small. If the molal concentration is denoted by C_i, Equation (2a) becomes:

$$\mu_i^{(w)} = \mu_{i,o}^{(w)} + RT \ln C_i \tag{2b}$$

where the superscript w denotes aqueous solution. Let us consider a multicomponent solid initially in a state of chemical equilibrium. $\mu_i^{(s)}$, the chemical potential of species "i" on the surface is equal to $\mu_i^{(b)}$, the chemical potential of the same species "i" anywhere in the bulk:

$$\mu_i^{(s)} = \mu_i^{(b)}, \quad t < 0 \tag{3}$$

When at some time t set equal to zero, the solid specimen is suspended into an aqueous solution, the waste form-leachant system represents a heterogeneous system consisting of two or more phases, not in a state of chemical equilibrium, and $\mu_i^{(w)}$, the chemical potential of species "i" in the aqueous phase is, in general, different from $\mu_i^{(s)}$:

$$\mu_i^{(w)} \neq \mu_i^{(s)} = \mu_i^{(b)}, \quad t = 0 \tag{4}$$

The above inequality in chemical potentials leads to a flux of mass between the surface and the solution. Release of species "i" from the surface, in turn, tends to decrease $\mu_i^{(s)}$, establishing a gradient in the chemical potential of species "i" in that part of the solid adjacent to the surface, thereby activating a bulk diffusion in the solid material.

These principles apply to species initially present in the leachant and in the solid. Species from the solid and from the leachant also interact to form new species both in the leachant and in the solid. Description of the chemical changes in the leachant can be based on purely thermodynamic grounds since reactions in aqueous solution are sufficiently fast so as to justify an equilibrium approach. On the surface and in the outer layers of the solid, the kinetics of reactions tend to be faster than the diffusional processes responsible for bringing the reactants together. Therefore, the rates of formation of new species are usually controlled by the rates of transport of the species participating in the chemical reactions.

The development of chemical potential differences in the leaching system will lead to kinetic phenomena across the liquid-solid interface and in the bulk of the solid phase.

Driving Force at the Liquid-Solid Interface

At any time t, the chemical force driving the release of a species "i" from the surface of the solid form is proportional to:

$$\Delta\mu_i(t) = \mu_i^{(s)}(t) - \mu_i^{(w)}(t) \tag{5}$$

If $\mu_i^{(s)}(t)$ is constant, saturation of the aqueous solution with regard to species "i" will eventually be achieved in a static test (no leachant renewal) and;

$$\mu_i^{(s)} = \mu_{i,sat}^{(w)} \tag{6}$$

which can be replaced in Equation (5) to give

$$\Delta\mu_i(t) = \mu_{i,sat}^{(w)} - \mu_i^{(w)}(t) \tag{7}$$

$\Delta\mu_i(t)$ represents the chemical force driving the release of species "i" until eventually the concentration of species "i" becomes equal to the saturation concentration.

Driving Force in the Bulk of the Solid

The flux of species "i" at some position inside the solid can be treated as a sum of terms describing ordinary (concentration) diffusion, thermal diffusion, pressure diffusion and forced diffusion. Ordinary diffusion is the most important bulk transport mechanism; it is based on the hypothesis that the rate of transfer of diffusing substance through unit area of a section is proportional to the concentration gradient measured normal to the section. It is expressed mathematically using Fick's first law:

$$Ji = -D \frac{\partial C_i}{\partial z} \tag{8}$$

there J_i is the rate of transfer per unit area and D is the diffusion coefficient.

Controlling Mechanism

Bulk and interface transport processes are driven by the differences in chemical potential $[\mu^{(b)} - \mu^{(s)}]$ and $[\mu^{(s)} - \mu^{(w)}]$. Depending on the kinetic characteristics of each process (developed in Section 5.2), either one of the

two mechanisms can be rate limiting at any time t after the solid was contacted with the liquid.

2. EXPRESSION OF LEACHABILITY

In leaching systems subjected to low rates of leachant renewal, where equilibrium between the solid and the liquid phases is approached, leachability is best described in terms of concentration in the leachate. Although equilibrium concentrations are indicative of the leaching driving forces, equilibrium leaching tests provide no information on the long term leachability since, as the system tends toward equilibrium, the driving force for the leaching reaction tends toward zero.

In leaching systems subjected to high rates of leachant renewal, a driving force is maintained between the solid and the liquid. Leachability, in this case, is represented by a flux $J_i(t)$, the mass of species "i" crossing the waste form - aqueous solution interface per unit area per unit time:

$$J_i(t) \equiv \left[\frac{M}{L^2 . T}\right]$$

The time dependent flux $J_i(t)$ can be normalized and expressed as a <u>waste form leach rate</u> by dividing it by f_i, the initial mass fraction of species "i" in the waste form:

$$L_i(t) = \frac{J_i(t)}{f_i} \tag{9}$$

where

$$f_i = \frac{m_{i,o}}{M_o} \tag{10}$$

m_o = initial mass of the waste form specimen [M]
$m_{i,o}$ = initial amount of species "i" in the waste form [M]

$L_i(t)$ has the same dimensions as $J_i(t)$, normally expressed in the following way:

$$L_i(t) \equiv \left[\frac{M \text{ (waste form)}}{L^2.T}\right] \qquad \text{based on species "i"}$$

The leaching data obtained in the laboratory from measurements of species leached can most easily be measured as a cumulative fraction leached, $F_i(t)$, expressed as the total mass of species "i" leached at time t over the initial mass of species "i" present in the specimen. The relationship between the leach rate and the cumulative fraction leached is as follows:

$$L_i(t) = \frac{M_o}{A} \frac{dF_i(t)}{dt} \tag{11}$$

where A is the surface area of the waste form specimen. The specimen surface area can be either the true surface area (e.g., BET surface area) or the geometric surface area. Waste forms are commonly compared on the basis of their geometric surface area (Mendel et al, 1981).

A thorough discussion of the various ways of expressing leachability from a theoretical and experimental point of view is given by Machiels and Pescatore (1982a).

4. FACTORS AFFECTING LEACH RATES

The factors that affect experimentally determined leach rates can be grouped as protocol related and field related factors. Protocol related factors will affect the quality and reproducibility of the data; they will not be discussed in this paper. Field related factors can be categorized according to their effect on the chemical potentials of a species "i" in the waste form bulk, $\mu_i^{(b)}$, on the surface, $\mu_i^{(s)}$ and in the surrounding aqueous solution $\mu_i^{(w)}$. Temperature affects the three chemical potentials. Factors that affect the bulk chemical potential $\mu_i^{(b)}$ will be discussed under waste form. The chemical potential of the species in the aqueous solution, $\mu_i^{(w)}$ is, of the three discussed in the last section, the only potential that can be controlled in a leaching test. It is a function of the chemical potential in the fresh

leachant, $\mu_i^{(\ell)}$, discussed under leachant characteristics and of the rate of leachant renewal, discussed under flow conditions.

Even under constant test conditions (leachant characteristics and flow), the leach rates will vary with time as a result of changes in the chemical potentials $\mu_i^{(s)}$ and $\mu_i^{(b)}$ due to incongruent leaching of various species and leachant waste form interactions. The variations of leach rates with time is discussed in Section 5.

4.1 Temperature

Leaching rates normally increase with temperature following an Arrhenius-type relationship. The general trend of reported temperature effects shows that a factor of 10 to 100 increase in leaching rate from ambient to 100°C is typical and indicates the importance of temperature control in leaching experiments (Mendel et al, 1981).

4.2 Waste Form

The main factor determining the mobility of a contaminant incorporated in a waste form is its chemical speciation (Cote and Hamilton, 1983). Soluble species are mobile while precipitated forms of the same species are immobile.

Blending of a waste with solidification additives may result in various chemical interactions that have the potential of reducing contaminant mobility. The following immobilization mechanisms were reviewed by Malone and Larson (1982): adsorption, chemsorption, passivation of waste particles, production of substitutions in insoluble crystalline materials and production of new insoluble compounds.

4.3 Leachant Composition

The effect of the leachant composition on leach rates is well documented. Several authors emphasize the importance of using site specific water when possible (Ham et al, 1979; Mendel et al, 1981; Roy, 1979; Stone, 1981). An alternative that is often preferred for simplicity or to allow interlaboratory comparison is use of distilled or deionized water. Pure waters have however

been reported to be more aggressive than actual groundwaters (Stone, 1981; Morgan et al, 1979; Lewis et al, 1981). Several synthetic leachant solutions have been developed through addition of reagents to distilled water in order to adjust the ionic strength, the pH and its buffering capacity, the redox potential and its buffering capacity and the complexation capacity.

pH is recognized as the leachant characteristic having the most important effect on leach rates (Mendel et al, 1981; Cote and Constable 1982; Welsh et al, 1981). pH control is effected through use of inorganic or organic chemical buffering systems, CO_2 pressurization or a pH-stat apparatus. Waters that might be contacted with hazardous wastes disposed of through shallow burial include groundwater (pH = 5.5 to 8.8 (Mendel et al, 1981)), acid rain (pH = 4 to 6) and in the case of codisposal with municipal refuse, sanitary landfill leachate (pH = 4.0 to 4.5 (Cote and Constable, 1982)).

Although the redox environment might have an effect on leach rates of ions whose mobility is sensitive to the valence (e.g., Cr and As), it is generally recognized that redox reactions are slow and that the redox environment is difficult to control in leaching tests (Lowenbach, 1978; Mendel et al, 1981).

Organics have been added to leachants to model the complexing capacity of field leaching waters (Ham et al, 1979). It has also been pointed out that organic buffering systems used for pH control might have the secondary effect of increasing the leach rates through complexation (Barkatt et al, 1981).

4.4 Flow Conditions

The leachant velocity (v) is defined as the volume of leachant contacted with the waste per unit waste surface area and unit time:

$$v \equiv \left[\frac{L^3}{L^2.T}\right] \equiv \left[\frac{L}{T}\right]$$

The waste surface area used to calculate v can be either the geometrical or the actual surface area but should be the same as the one used to calculate the leach rate.

v, which has velocity units, can be related to field disposal conditions. Aquifer velocities, as reported by Barkatt et al (1981) vary from 0.5 to 500 m/year. By contrast the velocity of water percolating through a hazardous waste form having a typical permeability of 10^{-7} cm/sec (Bartos and Palermo, 1977) under unit hydraulic gradient is 0.032 m/year.

The leachant velocity can also be expressed in terms of the conventional variables used to characterize laboratory leaching tests as shown below for intermittent and continuous flow tests.

Intermittent Flow Test

Also called a sequential batch test, an intermittent flow test involves changing the leachant at predetermined intervals. The leachant velocity for such a test can be defined in terms of the leachant renewal frequency $\emptyset(t) \equiv [1/T]$ and the specimen surface area to leachant volume ratio $\beta \equiv [1/L]$:

$$v(t) = \frac{\emptyset(t)}{\beta} \tag{12}$$

$\emptyset$ and β can be further defined

$$\emptyset(t) = \frac{1}{\theta(t)} \tag{13}$$

where $\theta(t)$ = duration of a leaching period (which can be variable with time) [T]

and

$$\beta = \frac{A}{V} \tag{14}$$

where A = specimen surface area $[L^2]$
V = leachant volume $[L^3]$

Continuous Flow Test

This test can be performed by immersing the specimen in a completely mixed reactor and ensuring continuous flow $Q(t) \equiv [L^3/T]$ through the reactor:

$$v(t) = \frac{Q(t)}{A} \tag{15}$$

Dependence of the Leach Rate on the Leachant Velocity

The leach rate, as defined in Section 3 is dependent on the leachant velocity; as the velocity decreases (from infinity), accumulation of leached species in the leachate decreases the leaching driving forces. This phenomenon, often referred to as saturation of feed back effect, has been observed by several investigators (Coles, 1981; Jackson et al, 1981); Macedo et al, 1982; Cote and Isabel, 1983).

The dependency of the leach rate on the leachant velocity can be illustrated by plotting a time invariant leach rate versus the leachant velocity (Figure 1). A time invariant leach rate can either be an instantaneous leach rate in the case of a dynamic system or a steady state leach rate. It is further assumed that no interaction between the leachant and the specimen - other than that of species "i" - changes the driving forces controlling the release of species "i" under various flow regimes.

The slope of the curve plotted in Figure 1 has concentration units:

$$\frac{\text{Leaching Rate}}{\text{Leachant Velocity}} \equiv \left[\frac{M}{L^2 T} \times \frac{T}{L}\right] \equiv \left[\frac{M}{L^3}\right]$$

The curve has two asymptotical limits where the sope can be interpreted as the concentration of the leached species in the reactor. Limit (1), the maximum leach rate, is obtained when the leachant velocity tends toward infinity. Under such flow conditions, there is no accumulation of leached species in the leachate (the slope of the curve tends toward zero) and the leaching driving forces are maximum. Limit (2) represents the saturation concentration of a species under the given leaching conditions. This limit can be reached for tests conducted under sufficiently low leachant velocity.

The functional dependence of the leach rate on the leachant velocity can be illustrated by considering a leaching test conducted in a completely mixed reactor (Machiels and Pescatore 1982b). A mass balance of the leached species "i" in the reactor leads to:

$$\frac{dC_i(t)}{dt} = \beta L_i(t) - \emptyset(t)\, C_i(t) \qquad (16)$$

assuming that the concentration in the feed is zero. At steady state, $dC_i(t)/dt = 0$, and the concentration in the reactor is given by:

$$C_i = \frac{\beta L_i}{\emptyset} = \frac{L_i}{v} \qquad (17)$$

If it is assumed that linear surface transfer (or dissolution) is the rate limiting leaching mechanisms, the leach can be expressed in the following way (Equation 40, Section 5.2):

$$L_i = L_o \left(1 - \frac{C_i}{C_{sat}}\right) \qquad (18)$$

where the superscript were dropped to simplify the notation. Combining Equation (17) and (18) leads to an expression for the functional dependence of the leach rate on the leachant velocity:

$$L_i = \frac{C_{sat}\, L_o\, v}{C_{sat}\, v + L_o} \qquad (19)$$

Equation (19), when plotted as L_i vs V, has the form of Figure 1, and the following limits become evident:

$$(L_i)_{v \to 0} = 0$$

$$(L_i)_{v \to \infty} = L_o$$

$$\frac{dL}{dv} = \frac{C_{sat}}{\left(1 + \frac{C_{sat}\, v}{L_o}\right)^2}$$

$$\left(\frac{dL}{dv}\right)_{v \to 0} = C_{sat}$$

$$\left(\frac{dL}{dv}\right)_{v \to \infty} = 0$$

5. LONG TERM LEACHABILITY INFERENCE

Inference on long term leachability consists in extrapolating the results of laboratory leaching tests to periods of time much longer than the test duration. Leach rates change with time as a result of the physical and chemical interaction between the waste form and the leachant. The surface area of contact can be modified through development of cracks (Perez and Westik, 1981) or sloughing (Kenna et al, 1979). Slow saturation of the matrix pores following immersion in the leachant will increase the effectiveness of bulk diffusion (Cote and Hamilton, 1983). Chemical reactions between the leachant and matrix constituents can result in the development of surface films that normally have the effect of reducing the leach rates (Lanza and Parnisari, 1981; Morgan et al, 1979). The fact that various chemical species leach at different rates produces two main types of effects. First, a surface layer depleted of the most leachable species will develop. The kinetics of steps involving species transfer through this surface layer can be rate limiting in the overall leaching process. Secondly, the most leachable species might play an important role in establishing the leaching environment through interaction with the leaching medium. Depletion of those species can cause drastic changes in the leaching environment and corresponding leach rate changes.

Evaluation of the change in leach rates with time can be done following two approaches. First, laboratory leaching can be accelerated to observe any change in mechanism that would occur with time. Secondly, rate limiting leaching mechanisms can be determined in terms of elementary processes to be used in mathematical models that would reflect changes in the leach rates with time. The potential of each approach will be further examined.

5.1 Accelerated Testing

Leaching can be accelerated by testing a specimen under environmental conditions such that leach rates are higher than those observed under reference environmental conditions (e.g., field conditions). Higher leach rates can be induced by maximizing the leaching driving forces through:

(1) conduction of the test at high temperature,
(2) use of high leachant velocity (c.f. Figure 1), and
(3) adjusting and buffering the leachant characteristics (pH, redox, etc.).

Higher leach rates will accelerate the development of the leached layer. Time dependent events, such as a pH shift in the leachate, due to the incongruent nature of the leaching process will also occur more rapidly.

A leaching acceleration factor (A_f) for species "i" can be defined as the ratio of test duration under reference conditions (t_R) and accelerated conditions (t_A) yielding the same cumulative fraction leached:

$$A_f = \frac{t_R}{t_A} \tag{20}$$

It is mandatory that leaching under the reference and accelerated condition be controlled by the same mechanisms. After the accelerated method has been validated with tests conducted under reference conditions, it can be used for longer periods of time and the results can be extrapolated using the acceleration factor.

There is confusion in the literature regarding the effect of increasing the waste specific surface area (i.e., through crushing) on the rate of the leaching process. U.S. EPA (1982) in their solidified waste delisting procedure, recommend grinding the sample to a particle size smaller than 150 μm. Lue Yen-Bower and co-workers (1979) proposed an approach toward long term prediction of leachability based on the use of high waste surface area to leachant volume.

According to Equation (12), crushing the waste results in a lower leachant velocity. Referring to Figure 1, it can be seen that this has the effect of reducing the leach rate. Crushing the sample therefore does not accelerate the leaching process as was defined above (it, in fact, retards it!). It does however speed up attainment of the saturating limits.

5.2 Modeling

Mathematical modeling allows identification and understanding of the mechanisms of release of contaminants from waste forms. Under certain conditions, it also permits extrapolation of test results.

Modeling can be done at various levels of sophistication. In empirical models, the data are fitted with an equation that has little or no relationship with the leaching mechanisms involved. Models based on mass transport phenomena appear to offer a means for achieving improved understanding of the basic processes governing the leaching process. Models based solely on mass transport are however also limited because they ignore the changes in leaching environment resulting from the interaction between the leachant and the waste form. If all major species that influence the characteristics of the leachate were modeled, mass transport models could be coupled with chemical kinetics/thermodynamics models to predict the changes in leaching environment. Models integrating the mass transport and chemical transformation aspects of leaching have not been developed yet.

5.2.1 Empirical Models

Several investigators have reported that the change of leach rate of a species "i" with time can be fitted to an expression of the form (Stone 1981; Godbee and Joy, 1974; Richardson 1981):

$$L_i(t) = a + b\, t^{-1/2} \qquad (21)$$

When this expression is compared to the relationships based on mass transport derived in Section 5.2.2, it can be seen that the time-independent term represents a dissolution mechanism or a linear surface transfer (Equation 36 or

40) while the negative square-root of time dependent term ($t^{-1/2}$) is associated with bulk diffusion (Equation 26). Equation (21) describes a leaching phenomenon controlled by diffusion for small values of time t; when t becomes large enough, a steady state is reached where dissolution or linear surface transfer becomes rate limiting. More complex leaching time dependence have also been observed such as a t^{-1} time dependence or a cyclic behaviour (Stone, 1981).

The leaching variability with time can also be expressed as a cumulative fraction leached by integrating the leach rate over time using Equation (11). Replacing the expression for $L_i(t)$ given by Equation (21) into Equation (11) and integrating yields:

$$F_i(t) = \frac{A}{M_0}(at + 2bt^{1/2} + c) \qquad (22)$$

The constant of integration c has been associated with the initial rapid release of surface species referred to as initial wash-off. Note that this term can also be negative to represent a delay in the leaching process.

An empirical model, the phantom dissolution model, proposed by Richardson (1981) treats the combined leach mechanisms as a dissolution process. With this model, the leachant is assumed to remove the leached constituents as if they were dissolved from the surface of a phantom solid that decreases with time as leaching proceeds. The depth of penetration of the leachant to the phantom surface at any time is given by an equation of the following type:

$$d = k_0 + k_1 t^{1/2} + k_2 t_2 \qquad (23)$$

where d is the depth of penetration calculated from the cumulative fraction leached data. Similarity between Equation (23) and Equation (22) is evident.

5.2.2 Mass Transport Models

Individual mechanisms that can control leaching rates include bulk diffusion, chemical reaction and surface transfer phenomena. Conceptual models governing leaching behavior have been reviewed by Claassen (1981). Models based on one controlling mechanism (e.g., bulk diffusion) can often be used to explain

the release observed in laboratory leaching tests but may lead to illogical or unrealistic predictions when the data are extrapolated to long times. Consideration of simple models however provides an understanding of the role played by individual mechanisms in more complex leaching models. Analytical solutions are available for some models including several different mechanisms. The complexity of the solutions often requires that asymptotical analysis be used to show leaching trends (Pescatore et al, 1982).

Before reviewing selected leaching models, the simplifying assumptions that allow derivation of simple analytical solutions will be reviewed.

5.2.2.1 Conceptual Leaching Models

Most mass-transport models are based on the implicit assumption that no chemical interaction between the leachant and the waste form occurs which would change the leaching environment with time. They describe the transport of one species resulting from concentration differentials between the solid and liquid phase and within each phase. Chemical transformation of that species (e.g., solubilization, adsorption) can also be represented as a reaction term in the mass balance equation.

A conceptual representation of the leaching phenomenon on which all the models presented below are based is shown in Figure 2. The waste form is assumed to be isotropic, unidimensional and semi-infinite. Species "i" in the bulk of the waste form is represented as a function of time and location and is assumed to be present in an immobile $[C^{(b)}_{i,im}(t,z)]$ and mobile $[C^{(b)}_{i,mo}(t,z)]$ chemical forms. Transport of species "i" within the solid takes place via bulk diffusion. No convective transport resulting from permeation of water through the solid is considered. The leachant, of time invariant characteristics $C_i^{(l)}$, is renewed with a velocity v (defined in Section 4.4). Since diffusion of leached species in the liquid phase is much faster than bulk diffusion, the concentration in the liquid $C_i^{(w)}(t)$ is a function of time only. Interface mass transfer results from a differential between leachate and surface chemical potentials. The presence of a surface layer is sometimes considered.

The limitations that these assumptions impose on the design of laboratory leaching tests will be examined in Section 6.

5.2.2.2 Bulk Diffusion

If species "i" is present in the matrix in its mobile form only, $C_{i,mo}^{(b)}(t,z)$, a mass balance shows that the net rate of transport is expressed by Fick's second law of diffusion:

$$\frac{\partial C}{\partial t} = D_e \left(\frac{\partial^2 C}{\partial z^2}\right) \tag{24}$$

where C is used for $C_{i,mo}^{(b)}(t,z)$ and D_e is an effective diffusion coefficient. D_e is unique to species "i" even though the subscript was omitted. The diffusion coefficient is referred to as effective because diffusion takes place in the liquid filling the interstices of a porous matrix. The liquid path length can therefore be much longer than that assumed by the model (Freybal, 1968). The effective diffusion coefficient D using a tortuosity factor T (Berner, 1980):

$$D_e = \frac{D}{T^2} \tag{25}$$

The retardation effect due to partial saturation of the matrix voids is also included in D_e (Cote and Hamilton, 1983).

A solution of Equation (24), for the case where the leachant velocity is high enough to maintain zero concentration of species "i" in the leachate $C_i^{(w)}(t) = 0$, was presented by Crank (1956):

$$L_i(t) = \frac{C_o}{f_i} \left(\frac{D_e}{\pi t}\right)^{1/2} \tag{26}$$

where $L_i(t)$ is a waste form leach rate as defined in Equation (9) and C_o is the initial uniform concentration (on a volumetric basis) of mobile species throughout the matrix. Note that $C_o/f_i = \rho$, the bulk density of the matrix.

The release of species "i" can also be expressed as a cumulative fraction leached by substituting Equation (26) into Equation (11) and integrating:

$$F_i(t) = \frac{2A}{V}\left(\frac{D_e t}{\pi}\right)^{1/2} \qquad (27)$$

5.2.2.3 Bulk Diffusion and Chemical Reaction

For the case where species "i" is present in both an immobile and a mobile form initially in a state of chemical equilibrium, leaching of the mobile form will establish a difference in chemical potentials to drive the following reaction:

$$\text{species "i"}_{im}^{(b)} \rightarrow \text{species "i"}_{mo}^{(b)}$$

If the reaction is fast, compared to the diffusion rate, the two forms of the species could be considered to be in a state of constant chemical equilibrium. If on the other hand, the reaction is slow, the kinetics of production of the mobile form has to be taken into account. The two cases will be discussed separately.

a. Instantaneous Chemical Reaction

A simple analytical solution to the mass balance equation can be obtained if the chemical equilibrium is represented by a linear adsorption isotherm:

$$\frac{C_{im}}{C_{mo}} = K_d \qquad (28)$$

A mass balance across a differential section leads to:

$$\frac{\partial C_{mo}}{\partial t} = D_e \frac{\partial^2 C_{mo}}{\partial z^2} - \frac{\partial C_{im}}{\partial t} \qquad (29)$$

which can be reduced to a form similar to Equation (24) by replacing C_{im} by $K_d C_{mo}$ [from Equation (28)]:

$$\frac{\partial C_{mo}}{\partial t} = \frac{D_e}{(1 + K_d)} \frac{\partial^2 C_{mo}}{\partial z^2} \tag{30}$$

The effect of the chemical equilibrium is to slow down the diffusion process. The solutions to Equation (30) are given by Equations (26) and (27) where D_e is replaced by:

$$D'_e = \frac{D_e}{1 + K_d} \tag{31}$$

These Equations show that the leach rate and the cumulative fractions leached are reduced by a factor of $(1 + K_d)^{1/2}$ when a fraction $1/(1 + K_d)$ of the initial concentration C_o is in a mobile form (Moore et al, 1975).

b. Kinetically Controlled Chemical Reaction

If the mobile species of initial concentration $C_{i,mo}^{(b)}(0,z)$ is being produced at a rate $k\,[C_{i,mo}^{(b)}(0,z) - [C_{i,mo}^{(b)}(t,z)]$, a mass balance across a differential section leads to:

$$\frac{\partial C}{\partial t} = D_e \left(\frac{\partial^2 C}{\partial z^2}\right) + k\,(C_s - C) \tag{32}$$

where for the sake of simplifying the notation, C represents $C_{i,mo}^{(b)}(t,z)$ and C_s, a saturation concentration, represents $C_{i,mo}^{(b)}(0,z)$. A solution of this differential equation was presented by Godbee and Joy (1974) for the semi infinite medium of uniform initial concentrations C_s and zero surface concentration. The leaching rate is expressed as:

$$L_i(t) = \frac{C_o}{f_i} (D_e' k)^{1/2} \left[\text{erf } (kt)^{1/2} + \frac{e^{-kt}}{(\pi kt)^{1/2}} \right] \quad (33)$$

where C_o is the total initial concentration ($C_{im} + C_{mo}$), erf is the error function (whose values are tabulated in most mathematical handbooks) and the effective diffusion coefficient D_e is now defined as follows:

$$D_e' = \frac{D_e}{(1 + K_d)^2} \quad (34)$$

where K_d is the initial value of the distribution coefficient given by Equation (28). Substituting Equation 33 in Equation (11) and integrating, an expression for the cumulative fraction leached is obtained:

$$F_i(t) = \frac{A}{V} (D_e' k)^{1/2} \left[\left(t + \frac{1}{2k} \right) \text{erf } (kt)^{1/2} + \frac{t}{\pi k}^{1/2} e^{-kt} \right] \quad (35)$$

Asymptotic analysis can be used to simplify Equations (33) and (35) at short and long time (Godbee and Joy 1974; Nathwani and Phillips 1980). For small values of kt (at short time or for k = 0), Equation (33) reduces to the simple diffusion model represented by Equation (26). For large values of kt, erf (kt) approaches unity and the leach rate as defined by Equation (33) reaches a steady state:

$$L_i \cong \frac{C_o}{f_i} (D_e' k)^{1/2} \quad (36)$$

This analysis shows that long testing periods are required to quantify the reaction constant k and that, if a chemical species is initially present in a mobile and immobile form, a steady state leach rate will eventually be reached.

5.2.2.4 Interface Mass Transfer

There are, in general, three resistances to the movement of species "i" across the interface: the solid phase, the liquid phase and the interface

itself. If the interface resistance is neglected, the entire two-phase mass-transfer effect may be measured in terms of an overall mass-transfer coefficient K (Treybal 1968):

$$J_i(t) = K \left(C_{i,sat}^{(w)} - C_i^{(w)}(t) \right) \tag{37}$$

where $C_{i,sat}^{(w)}$ is the saturation concentration of species "i" in the liquid. Since $C_{i,sat}^{(w)}$ is the liquid concentration when the system is at equilibrium, it represents the chemical potential of the surface species (c.f. Section 2).

The flux across the interface can be expressed as a waste form leach rate through use of Equation (9):

$$L_i(t) = \frac{K}{f_i} \left(C_{i,sat}^{(w)} - C_i^{(w)}(t) \right) \tag{38}$$

The leach rate will reach a maximum value L_o when $C_i^{(w)}(t)$ tends toward zero:

$$L_o = \frac{K}{f_i} \left(C_{i,sat}^{(w)} \right) \tag{39}$$

Replacing the value of K obtained from Equation (39) into Equation (38):

$$L_i(t) = L_o \left(1 - \frac{C_i^{(w)}(t)}{C_{i,sat}^{(w)}} \right) \tag{40}$$

This expression is similar to the one obtained by Machiels and Pescatore (1982a) using a chemical kinetics approach.

When $C_{i,sat}^{(w)}$ is small, saturation is expected to be reached rapidly and the kinetic information contained in L_o (or K) is unimportant. Since $C_{i,sat}^{(w)}$ is a thermodynamically defined quantity, the release of species "i" is thermodynamically or solubility limited. When $C_{i,sat}^{(w)}$ is large, the release of species "i" is mainly controlled by L_o (or K); the leach rate is then kinetically controlled.

b. Matrix Dissolution or Corrosion

If species "i" is structurally a major component of the waste form, release of that species in the leachate leads to a structural breakdown of the matrix, a process which is referred to as dissolution or corrosion. The kinetics of the process can be represented by a network dissolution velocity u [L/T], defined as the volume of solid material being dissolved per unit time, per unit surface area of solid exposed:

$$u(t) = L_i\ (t)\ \frac{1}{\rho} \tag{41}$$

where ρ is the bulk density of the waste form [M/L^3]. Substituting Equation (40) into Equation (41) and defining the maximum network dissolution velocity as $u_o = L_o/\rho$, we obtain:

$$u(t) = u_o\ (1 - \frac{C_i^{(w)}(t)}{C_{i,sat}^{(w)}}) \tag{42}$$

To derive an expression for the cumlative fraction leached for network dissolution controlled leaching using Equation (11), the time dependence of $C_i^{(w)}(t)$ would have to be replaced into Equation (40). In the simple case where $C_{i,sat}^{(w)} >> C_i^{(w)}(t)$, $L_i = L_o$ and:

$$F_i\ (t) = \frac{A\ L_o}{M_o}\ \ dt \tag{43}$$

Multiplying by V/V, replacing $\rho = M_o/V$ and $u_o = L_o/\rho$ (Equation 41) and integrating yield:

$$F_i(t) = \frac{A}{V}\ u_o\ t \tag{44}$$

which expresses that the cumulative fraction leached of any species "i" is independent of the concentration of that species in the waste form.

6. FACTORS TO BE CONSIDERED IN THE GENERATION OF LABORATORY LEACHING DATA

Selection of laboratory leaching test conditions must compromise between simulating field conditions and meeting the intended use of long term inference. Perfect simulation of field conditions in a laboratory test is not desirable since it would provide information for the test duration only.

Leaching tests can be used to obtain both equilibrium and kinetic data. In equilibrium tests, saturation can be reached faster if the waste is first crushed and the minimum liquid to solid ratio is used. Kinetic data can be obtained by running both static and dynamic tests. In a static test, the leachant is the same for the duration of the test and aliquots are taken at frequent intervals. The method poses a problem for sparingly soluble compounds (such as metal hydroxydes under high pH conditions) since the range within which concentrations can be measured (from the analytical detection level to the saturation limit) is often too narrow to obtain the required amount of data needed to calibrate mathematical models. In dynamic tests a leachant velocity is maintained (either by continuous or intermittent flow) and the kinetic data is obtained by measuring the cumulative fraction leached.

The main limitations imposed on the selection of laboratory test conditions arise from the hypothesis used in mathematical models selected to interpret the leaching results. All mass-transport based models assume a constant leaching environment. This can be obtained either if the waste or the leachant controls the leaching environment. The waste will control the leaching environment when a mild leachant is used (e.g., distilled water) in conjunction with a low leachant velocity. On the other hand, the leaching environment can be adjusted by using a buffered leachant with a higher leachant velocity. The effects of the waste-leachant interactions on the leachant environment were discussed by Barkatt et al (1981).

Leaching tests have to be designed to respect the initial and boundary conditions of the mass balance equation used to interpret the leaching data. Typically, the mass balance equation including bulk diffusion is solved with the following conditions (Section 5.2.2):

initial condition

$t = 0,\ 0 < z < \infty \quad C = C_o$

boundary conditions

$t > 0 \quad z = \infty \quad C = C_o$

$t > 0 \quad z = 0 \quad C = 0$

The initial condition of uniform concentration can be respected by carefully preparing the specimens on the laboratory as discussed in the American Nuclear Society (1981) standard.

The boundary condition of semi-infinite geometry is met by most test samples except possibly for finely crushed materials (Pescatore and Machiels, 1982). Criteria for verifying the departure from semi-infinite geometry were derived by Pescatore and Machiels (1982) and the American Nuclear Society (1981).

The most critical condition is the boundary condition of zero surface concentration. This condition is used in order to obtain a simple analytical solution to the diffusion equation (Crank 1956). It can only be approached by using a very high leachant velocity in which case concentration of the leachate (e.g., through evaporation) might be necessary to allow analytical detection. Pescatore et al, (1982) presented a model in which the surface concentration boundary condition is expressed via a mass balance in the leachate taking into account the leachant velocity.

It is obvious from the above discussion that a single leaching test can not provide the information required to calibrate complex mathematical models. Information of both a thermodynamic and kinetic nature is required. Furthermore, solution of multiple parameter models require data generated under various flow conditions. Finally, it is often desirable to investigate the leaching behaviour under different environmental conditions (temperature, pH, etc.). The complexity of the situation has lead several organizations to propose batteries of tests to meet these requirements (American Nuclear Society 1981; International Standard Organization, 1979; Strachan et al 1981; Barkatt et al 1981).

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LIST OF SYMBOLS

a = chemical activity or empirical constant (Equations 21 and 22)
b = empirical constant (Equations 21 and 22)
c = empirical constant (Equation 22)
d = depth of penetration of the leaching front [L] (Equation 23)
f = mass fraction
k = empirical constant (Equation 23) or kinetic constant (Equation 32)
m = mass [M]
t = time [T]
u = network dissolution velocity [L/T]
v = leachant velocity [L/T]
z = space coordinate [L]
A = surface area of solidified waste specimen [L^2]
A_f = leaching acceleration factor [ ]
C = concentration [M/L^3]
D = diffusion coefficient [L^2/T]
F = cumulative fraction leached [ ]
J = mass flux [$M/L^2 \cdot T$]
K = mass transfer coefficient [L/T] (Equation 37)
K_d = partition factor (Equation 28)
L = leaching rate [$M/L^2 \cdot T$] or space dimension
M = mass dimension
M_o = initial mass of the waste form specimen [M]
P = pressure [$M/L \cdot T^2$]
Q = leachant flow rate [L^3/T]
R = gas law constant (8.314 J/mol·°K)
T = temperature or tortuosity factor of time dimension
V = leachant volume (L^3)
β = specimen surface area to leachant volume ratio [1/L]
θ = duration of a leaching period [T]
μ = chemical potential
ρ = bulk density of the waste specimen [M/L^3]
ϕ = scalar potential (e.g., redox) or leachant renewal frequency

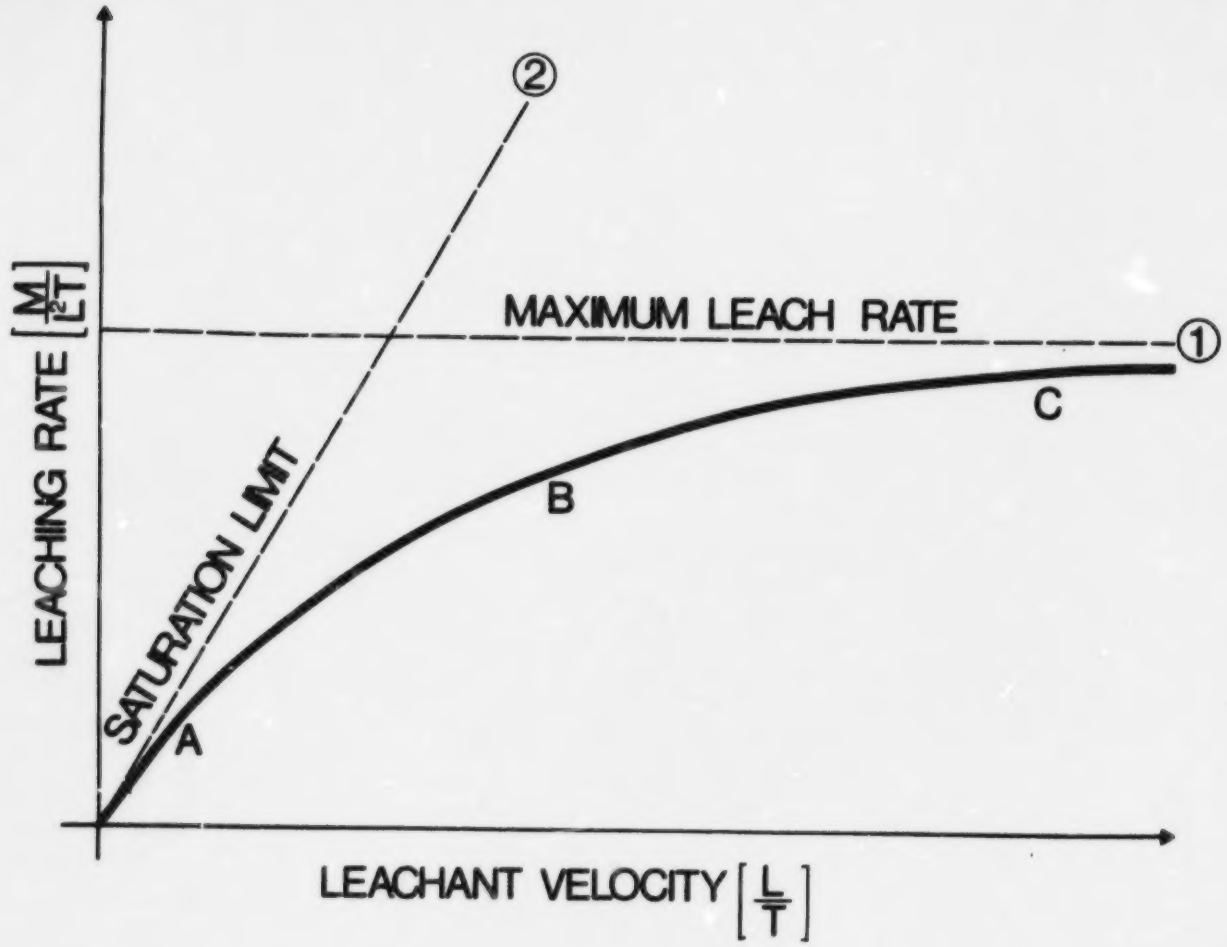

FIGURE 1. DEPENDENCY OF THE LEACH RATE ON THE LEACHANT VELOCITY

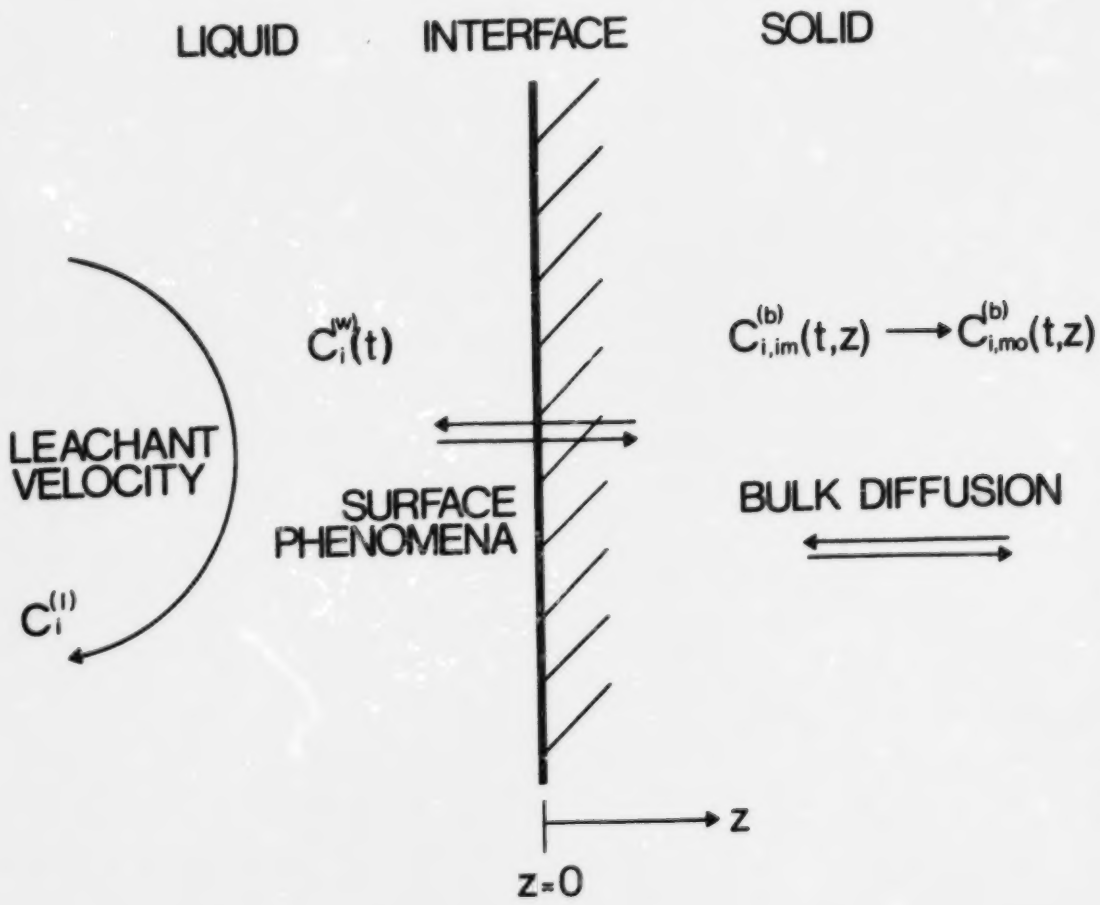

FIGURE 2. CONCEPTUAL LEACHING MODEL

DISCUSSION

S. Hrudey - First of all, Pierre, let me congratulate you on an excellent approach, that's quite imaginative. Just the one question: you mentioned using 2" cubes because you had some knowledge of its surface area. Referring to Dr. Tittlebuam's electron micrographs with all those little dibbles and so on and a very complex surface area, how are you dealing with those two factors?

P. Cote - It's been an established practise to use the geometrical surface area to express leaching results or leach rates and it's, as you mentioned, an arbitrary decision and it's going to be valid as long as everybody does the same thing. Now, you could express the leach rates using the actual surface area, the B.E.T. surface area, but all it would do, it would change the orders of magnitude of the results.

S. Hrudey - I guess the factor that's involved would be that, as long as you have the same relationship between geometric surface area and the actual surface area.

P. Cote - It will change from product to product. It's probably because some people have proposed cumulative fraction leached as being a much better way of expressing leachability results because they don't involve the use of surface area. But that is not as useful then, when you want to model. You always end up in a situation where you have to define a ratio between the volume of leachant and the surface area of waste in contact. So eventually you have to use some surface area, either the actual or the geometrical surface area.

N. Mossholder - I'm not sure I'm going to articulate this very well. But sitting here, looking at the modeling, it was very interesting and I think very good for understanding what's happening. But my source of disquiet is, what does it mean in terms of evaluating a product in a particular environmental situation. I found myself thinking, gee, it would be very nice to have a very rapid flow of ground water, because then even though the leaching rate is maximized, the concentration of leachate is minimized. That led me to the question of what we're really looking at when we look at the models in terms of evaluating a product. We're trying to minimize leaching rate, or are we trying

minimize leachate concentration. And that becomes very important when you start talking about accelerated testing of actual products. So can you respond to that even though it wasn't phrased in the form of a question.

T. Bridle - I don't know if I'll answer any better. But the approach that Pierre is taking is fundamental, agreed. And it is difficult to relate that to industrial practise or what's going to happen in the real world. I think we have been caught up in a situation where we're using short term tests that give you a concentration, and that's even more difficult to relate to the real world. I think we have the potential and we're going down the right road now. We're developing a fundamental property which is characteristic of a waste and how it is being processed. And tomorrow maybe it will come up when Pierre discusses those diffusivities, which can also be expressed in a negative logarithm, it's just a leaching index, LX value. It may provide a far better way of comparing things and this is coming up tomorrow again, rather than using a one shot static test that gives you a concentration that's almost impossible to define what it means. Whereas here if you understand or if you can show from long term leaching tests, and we are doing work in Burlington where this work is still continuing and we're just leaching and leaching and leaching to see if there is a break in the mechanism. But if you can show that diffusion controls for a long long time and then you can model on a leachability index, you have now a fundamental parameter of a solidified product and therefore you compare one product to the other. More importantly, you may be able to extrapolate, you have now a factor that's got time involved and you can make some predictions with what will happen in time, provided the leaching mechanism doesn't change over time. And that's a critical factor and that's why you need those acceleration factors. We cannot continue leaching for fifty years to get fifty years of leaching data. We have to define a method of accelerating the leaching phenomenon.

N. Mossholder - Please don't misunderstand me, I'm not degrading the work at all because I think it's a beautiful piece of science to lay the framework for understanding exactly what's going on. My only concern is that we understand what our objective is before we start launching into testing programs.

P. Cote - You cannot divorce that also from the hydrogeological studies. This provides the information that they need to calculate dilution factors or attenuation factors, rather than just using concentration in a static test.

J. Rousseaux - I think, Pierre, we could express your results in a slightly different way. Instead of plotting the rate of leaching as a function of square root of time we could put the reduced concentration as a function of time, a function of the square root of time, which gives you the percentage of leaching of the metal involved in this experiment. And if you plot this reduced concentration as a function of the square root of time you would get a straight line whose equation is really very easy to define. To answer Nelson's question, knowing the mathematical form of this equation you could predict very easily the long term leaching rate.

P. Cote - In fact it's just a matter of mathematical expression. Once you fit a model you can use it to predict what the cumulative fraction leached will be. You could also use the same model to predict what the concentration will be at any time at the boundary of the solidified waste. That's a good point. I took it for granted.

SECTION IV

CURRENT EXPERIENCE WITH TESTING SOLIDIFIED WASTES

A. Liem - Good afternoon. I'll be moderating this afternoon's session which is on current experience with testing solidified wastes. I think in a meeting like this, it's impossible not to involve the vendors in the discussion. For any test protocols, what we are about to propose, to be acceptable, I think they have to be acceptable also to the vendors, in addition to being sound technically and so on. So with that in mind, we have invited a number of vendors to present their experience, in particular with testing methods and their results and interpretation. We also have other companies that have been invited, but not making presentations. To those, to anybody else, you are welcome to make contribution to this session. I would like to call the first speaker Mr. Hudson Buzbee from Chemfix in Kenner, Louisiana. Mr. Buzbee is the vice-president for Planning and Development.

CURRENT EXPERIENCE WITH TESTING SOLIDIFIED WASTES

Hudson Buzbee
Chemfix Technologies Inc.

No manuscript received.

DISCUSSION

P. Chaudhuri - I probably missed just what is this process that you call Chemfix. You haven't touched any of that.

H. Buzbee - The Chemfix process is a process that's been around since the early 1970's, 1971. It is in effect a cement soluble silica process. There are waste modifications done prior to, or as a pretreatment step in many cases, but in general the Chemfix process is a cement soluble silica process.

G. Fell - Hudson, before I ask you a question, Dr. Liem may I thank you for an excellent lunch. At least those around me didn't eat it out a lot, they were too tired, so would you thank the staff particularly how pleasant they did it. Hudson, on that point as we're talking about people, one of the things I know you didn't get into and wanted to, was this "representative". What was your personal relationships with the federal EPA and particularly with the State. You were talking about the need for representative sampling. They came back to you, so what is your relationship, I mean we are talking about the practicalities.

H. Buzbee - It is a very interesting application we have here, in that this company, our client, had submitted information to EPA before and it was determined during review of that information, that they had not submitted data based upon representative samples. So the EPA was a little gun shy in saying, "Well, why would you submit representative works the second time around". Chemfix got involved and went out. The previous work was done on grab samples, random pattern, maybe 15 samples instead of our 100 samples. Then after we had submitted information saying we strongly believe this to be representative, EPA said, "Well, go out and here are 15 random points that you have sampled before, 15 of your 100. Go sample them again and come back to us and say, were your results actually valid." In our case here, most of the lead and chrome analyses, for example, were very similiar if not a little higher the first time we looked at them. So, we are very pleased that we showed ourselves that we can do representative work.

TESTING OF CHEMICALLY SOLIDIFIED WASTE FOR DISPOSAL IN SANITARY LANDFILLS OR ON-SITE MONOFILLS

Jesse Conner
Chem Technics Inc.

MANUSCRIPT BY JESSE CONNER

INTRODUCTION

Most organizations involved in chemical fixation and solidification work operate primarily at central treatment and disposal facilities, or when treating waste on-site*, dispose of it at a central facility. This tends to limit and/or simplify the choices of test parameters for the following reasons:

- Properties of the leachant -- i.c., rain, surface water, ground water -- are known or can be estimated and reproduced.
- Environmental impact of the site is known.
- Regulatory requirements and attitudes are known and relatively constant.
- Usually, a single solidification process technology is used for the complete range of wastes treated.
- The variety of wastes treated is often, although not always, limited.

In the case of a company offering chemical fixation/solidification (CFS) processes, products and services to generators and others for on-site use, the situation is quite different. The disposal site may be on-site or off-site, monofill or mixed fill; with mixed fill the other waste(s) may be construction debris, domestic refuse, or other industrial wastes. Thus, the leachants which will actually be in contact with the wastes vary widely, and are not well defined in many instances. Similarly, detailed knowledge about the overall environmental impact of the site is not normally very good. Laws, regulations and attitudes vary widely from state to state and from one locality to another within a state. In marketing custom-engineered CFS systems, a number of different chemical processes are used, and a very large variety of wastes are treated.

* The term "on-site," for the purpose of this discussion, means at the site of waste generation, or at a cleanup or spill location.

These differences from the more common approach to marketing CFS technology heavily affect the testing area. A wider variety of testing protocols are required. More characteristics must be tested for. Sample preparation runs into some special problems. Results and their interpretation by regulators and others vary widely. The use of different chemical systems makes the interpretation of test results with respect to long-term stability more complex. Quality control test protocols must be adapted for use by technicians who are not expert in solidification or in this type of testing.

TEST METHODS IN USE BY CHEM-TECHNICS

1. USEPA EP Toxicity Test. All "detoxified," formerly hazardous, solidified wastes are subjected to this standard (in the United States) test method. Except in special cases, or where required as a specification test, the alternate "Structural Integrity Procedure" is not used. Instead, the sample is crushed to pass through a 9.5 mm sieve; this procedure normally results in a range of particle sizes from 9.5 mm to 150 µm (No. 100 sieve). In the case of fibrous or plastic solids, the solid is cut to produce pieces which pass through the 9.5 mm sieve.

2. USEPA Multiple Extraction Procedure (Federal Register Vol. 47, No. 225, Monday Nov. 22, 1982). This test has been required by USEPA in temporary exclusion ("delisting") petitions. It is also being used by at least one state -- Georgia -- as a specification test for "reclassification" of formerly hazardous wastes as non-hazardous solids suitable for sanitary landfill.

3. US Army Corps of Engineers falling head permeability test (triaxial). Used for determination of coefficient of permeability for evaluation as landfill cover material.

4. Unconfined Compressure Strength. Measured on as-cast, monolithic samples with Soiltest Penetrometer Model CL 700 for routine quality control and evaluation testing. For specific requirements, standard laboratory compression tests and other soil laboratory physical tests are run as required.

5. Water Resistance Tests. Monolithic samples are covered in a closed container with D.I. water and evaluated after various periods of time for disintegration, softening, edge rounding and other changes in physical appearance. Tests are typically run for 60 days, but have been continued as long as two years.

OTHER METHODS USED IN THE PAST AND/OR RUN NOW ON DEMAND

1. Downflow Column Leaching Test, using D.I. water. This test is run in a continuous mode at a (nearly) constant head at a flow rate of one ml. per minute if the permeability of the packed column allows. Normal run time simulates 220 cm. of rainfall. Also used with acid, alkaline or other leachants.

2. Anaerobic Sanitary Landfill Co-disposal Test. Continuous "column type" test with nitrogen purged D.I. water through alternate layers of solidified waste and milled domestic refuse.

3. ASTM Method D3987 Shake Extraction Test.

4. Pennsylvania DER Leaching Test. D.I. water shake for 48 hours (1977).

5. New Jersey DEP Leaching Test. Acetic acid shake test, 24 hours (1976).

6. Minnesota Test. Buffered acetic acid or D.I. water shake tests, 24 hours (1976).

7. Texas Test. D.I. water static test, seven days (1976).

8. Illinois Test. Acetic acid at 100°C for 5 minutes.

9. Japan Ministry of Public Welfare Test. D.I. water buffered with HCl or NaOH to various pH's (as appropriate), shaken for six hours. Sample particle size 0.5 to 5.0 mm.

10. California Waste Extraction Test (WET). 0.2M sodium citrate at pH 5.0 ± 0.1 flushed with nitrogen before test. Shake test for 48 hours in sealed container (Revised 9/15/83).

Most of the tests are no longer in use, and some have never been officially sanctioned or widely used. Nevertheless, we do have experience with them, which can be useful in understanding the leaching phenomenon and in formulating future protocols.

TYPICAL RESULTS

Several sets of data are presented below to illustrate typical results achieved with several test methods. In Table 1, EP Toxicity test data is presented on both laboratory and field-produced solidified waste pickle liquor sludge. For most constituents, the production solid gives slightly better results. It should be noted that the differences between lab and field can be as much as an order of magnitude. However, part of this is due to test and analytical variations, which in our experience can be 25% or more in the same laboratory, and much higher between different laboratories. In the case of chromium, when the total chromium is well below specification limits, as it is in this case, we do not do the hexavalent chromium analysis.

Table 1

US EPA EP TOXICITY TEST
SOLIDIFIED NEUTRALIZED WASTE PICKLE LIQUOR SLUDGE

Constituent	Concentration of Constituent in Untreated Waste	Concentration of Constituent Leached From Solidified Waste	
		Laboratory	Field
Arsenic	0.140	0.0013	< 0.5
Barium	27.4	3.17	0.22
Cadmium	2.91	0.054	0.021
Chromium, total	15950.	0.364	1.00
Chromium, hexavalent	6.86	--	--
Lead	88.8	0.50	0.399
Mercury	0.260	0.0017	0.003
Selenium	2.6	0.0007	0.006
Silver	7.28	0.080	0.021

All results in mg/L
< = less than
- = not analyzed
ND = not detected

Table 2 gives typical results running the Multiple Extraction Procedure on solidified waste -- in this case, an electroplating sludge. For this test, hexavalent chromium was not reduced to the trivalent state by pretreatment, as would normally be done, because we wanted to determine the leachability of the hexavalent state in the MEP. Results show that only about 4% of the hexavalent chromium was leached out during the test, half of this in the first step which is really the EP. The fall-off in leaching rate with each successive step is the typical pattern which we have found in all sequential tests, batch or column. With MEP, however, the drop from step 1, the EP, to step 2, synthetic acid rain solution, is especially sharp. Our overall experience with the MEP to date is that the EP step is controlling from the standpoint of meeting the leaching specifications.

One problem with the MEP protocol is the sample preparation requirement, which specifies grinding the solid to -100 mesh (<150 μm). With many solidified wastes, this is not possible. These solids have high water content and a somewhat plastic nature, which causes them to smear during grinding and sieving. Fibrous wastes are also a problem in this respect. EPA has agreed that if the solid cannot be reduced to <150 μm, the attempt be documented and the final size distribution recorded, and this will be acceptable. We have found that most solids can be ground to -20 mesh (about 1 mm).

Table 2

US EPA MULTIPLE EXTRACTION PROCEDURE (MEP)
SOLIDIFIED ELECTROPLATING SLUDGE

Concentration in Leachate (mg/L)

MEP STEP	C6*	Cr	Ni	Total Cn	Free Cn	Initial pH	Final pH
1 (EP)	3.0	4.6	.54	.25	.07	12.1	5.10
2	.9	.95	<.05	<.05	<.05	10.2	10.9
3	.7	.8	<.05	<.05	<.05	10.2	10.5
4	.5	.5	<.05	<.05	<.05	10.0	10.5
5	.3	.3	<.05	<.05	<.05	9.6	10.7
6	.2	.2	<.05	.05	.05	9.8	10.1
7	<.13	.13	<.05	.05	.05	8.5	10.0
8	<.10	.10	<.05	.05	.05	9.7	10.0
9	<.14	.14	<.05	.05	.05	7.0	9.6
10	<.09	.09	<.05	.05	.05	9.4	10.0
DI Water				.71	.71	12.1	11.9
Analysis of Raw 140	5650		5990	95	75	Cd .5	

* Not pretreated for Cr^{+6}

An interesting comparison with the present batch-shake type specification tests is a pre-RCRA test used for many years in the USA -- the column leaching test described briefly above. Leaching results on a solidified municipal sewage sludge, using the column test, are given in Table 3. While the D.I. water used in this test is less aggressive than the EP, especially in metal leaching, the test physically simulates actual landfill conditions much better than batch-shake tests.

Table 3

COLUMN LEACHING TEST
SOLIDIFIED SEWAGE SLUDGE

Constituent	Concentration of Constituent in Untreated Waste	Concentration of Constituent Leached From Solidified Waste Column Leaching Test* - Centimeters of Leaching (Rainfall Equivalent)			
		62	124	186	248
Biological Oxygen Demand	5500	430	100	50	<25
Cadmium	9.2	<0.10	<0.10	<0.10	<0.10
Calcium	>400	11	34	35	32
Chemical Oxygen Demand	>200,000	2500	600	1300	900
Chloride	>75,000	200	100	50	25
Total Chromium	210	<0.10	<0.10	<0.10	<0.10
Copper	190	7.9	1.5	0.50	0.25
Cyanide and related	10	0.50	<0.10	<0.10	<0.10
Iron	920	<0.10	<0.10	<0.10	<0.10
Lead	14	<0.10	<0.10	<0.10	<0.10
Mercury	<0.10	<0.10	<0.10	<0.10	<0.10
Nickel	10	1.5	<0.50	<0.10	<0.10
Nitrogen-Ammonia	1500	2.9	2.5	3.5	4.5
Nitrogen-Nitrate	1.0	<0.10	<0.10	<0.10	<0.10
Nitrogen-Nitrate	300	5.0	4.0	0.50	0.25
Phenol and related	3.5	0.50	<0.10	<0.10	<0.10
Phosphate	7000	16	6	4.5	2.0
Potassium	>100	43	46	16	7.5
Sulfate	-	180	40	25	20
Total Organic Carbon	17,000	330	100	<25	<25
Zinc	410	<0.10	<0.10	<0.10	<0.10

All results in mg/L
< = less than
- = not analyzed
ND = not detected

* The above data reflects the analysis of leachate prepared according to a Column Leaching Test using distilled water as the leachant.

NEEDS IN DEVELOPING TEST PROTOCOLS

From the vendor standpoint, and especially ir view of Chem-Technics' approach to CFS technology, there are certain definite needs for new and improved test protocols. We feel that no single test method is suitable for general use, except perhaps as a screening procedure. In any case, in the USA many states will require their own tests as California already has done, and these will be in addition to US EPA minimum requirements. However, the development of a battery of tests will allow evaluation under a wide range of environmental conditions might help prevent the uncontrolled proliferation of test methods.

Specifically, we would like to point out two test needs which exist now. The first is a laboratory test which will better simulate or model the condition of commingling of wastes in a landfill, especially that of solidified industrial waste and domestic refuse in a sanitary landfill. This is a common occurrence in the USA and is of great concern to state regulators who feel that the EP is not a satisfactory method.

Second is the need for quick, simple, inexpensive estimation tests to be used for quality control and process development screening. This type of test would not be used as a specification test for regulatory approvals or other such purposes, but rather for internal use by CFS vendors and other investigators in this field.

DISCUSSION

D. Friedman - Have you done any work to look at correlation between tests that can be done in a few hours versus the longer term tests on the QC type testing.

J. Conner - Very little Dave. We are just not in the test development business. We'd like to see somebody do it though.

D. Friedman - Has anybody done any?

T. Bridle - Just a quick question to you either Jesse or Dave. I'm just looking at your table 2 here where it appears that on the MEP after the first extraction procedure your pHs are back up at 11. Do you not add the 2 miliequivalents of acid per gram of waste after the first test?

J. Conner - Yup.

T. Bridle - You do?

J. Conner - Yes, we do. Oh, that's in the MEP. No, he's talking about the first step, the EP step.

T. Bridle - The second and subsequent dilutions, pHs are back up at 11 again.

J. Connor - I'm sorry, no, you start out with a specific leachant but it is not adjusted during the test so the pH goes to whatever natural pH it will go to. In this case, these are primarily alkaline systems so they will be alkaline.

CURRENT EXPERIENCE WITH TESTING SOLIDIFIED WASTES

J. Thompson
Dravo Lime Company

No Manuscript Received

DISCUSSION

A. Liem - How do you actually take those pictures? Before or after curing and setting, and how are they mounted?

J. Thompson - Some were taken before they're cured. It depends on what we're trying to see. Often, for scanning electron micrographs we either use a very low viscosity epoxy or else, if the sludge can't be simply dried and to look at the fractured surface, then the same is true for the fixed materials, which usually are stable enough that you can put some of the sludge on a stub and float it off onto a gel and begin to ion mill it down to a point where you can look through it. It usually takes us close to between 80 and 100 hours of ion milling time to get the thing down thin enough that we can look through it.

P. Cote - You sort of made the equation between dehydration reaction going on and stabilization, and it's not clear to me that it's as easy as that. It's not because the physical strength increases and the hydration reaction goes on; it's not because that happens that the waste toxic contaminants are necessarily insolibulized or immobilized.

J. Thompson - One thing is, that by the number of small pore spaces that are created between the hydration fingers, if you will, those crystallites that grow, it's much more difficult for water to migrate through the sample. So that changes the leachate rate, it takes a much higher pressure to drive water through the stabilized sample. In some cases there appears to be a chemical reaction between the hydrate materials and what it is you're trying to stabilize, other cases there's not. That just depends on what it is your trying to stabilize.

L. Katsanis - What is the product, the composition of it. I'm just trying to determine the chemistry in my own mind.

J. Thompson - Calcilox?

L. Katsanis - Yes.

J. Thompson - It's a combination of blast furnace slag which is ground to about 4,000 square centimetres per gram, and in some cases, some people add lime, to get the pH up, to the overall system before it stabilizes. It does not work in an acid environment, so in some cases with coal fines refuse, normally acidic with water by themselves, we have to get the pH up to 10 or 11 or something to stabilize the thing.

THE THEORY AND DESIGN OF STRUCTURAL LANDFILL AS APPLIED TO STABILIZED HAZARDOUS WASTES

Hugh Mullen and J. Colussi
Envirosafe Services, Inc.

MANUSCRIPT BY H. MULLEN & J. COLUSSI

EXECUTIVE SUMMARY

Each stabilization process is unique, develops different properties in the stabilized material and uses different mechanisms to protect the environment. A stabilization process is a system and the material cannot be evaluated in isolation from the method of placement and disposal. No single set of test procedures and values will suffice to evaluate all processes. The evaluation method must be tailored to the specific stabilization process.

The CSI Poz-O-Tec process utilizes a pozzolanic reaction to produce a cementitious monolith of high strength and low permeability. The design and operation of the associated structural landfill are integral parts of the process and test results must be evaluated in conjunction with the fill design. Specific tests used in the CSI evaluation are unconfined compressive strength, falling head permeability and ASTM Method A and EP leaching tests. A test highly recommended for overall evaluation is the CSI Runoff Test.

INTRODUCTION

The assessment of the efficacy of a given stabilization process is complex and unique. That is because stabilization processes differ and utilize different mechanisms for the containment of contaminants. In the past, investigators have taken the simplistic attitude that one assessment protocol is applicable to all stabilized wastes. The objectives of this seminar, i.e., development of an assessment protocol..., perpetuate that mistaken concept. A proper assessment must evaluate the mechanisms utilized by the stabilization process under study. There is no universal test protocol. For example, one process may rely heavily on reduced permeability; for another, permeability is of no importance. A protocol requiring permeability determination is prejudiced against the latter process and in that case is inappropriate and meaningless. Each stabilization process should be evaluated by and only by the test procedures applicable to that process. Most evaluations to date have been prejudiced by the investigator's belief that he is more knowledgeable than the supplier of the process or a compulsive desire to oversimplify and develop a universal test protocol.

Previous Evaluations

Two examples of inappropriate and therefore erroneous evaluations of stabilization processes were the WES Report PB83-147983 entitled "Physical Properties and Leach Testing of Solidified/Stabilized Industrial Wastes" and the Oak Ridge National Laboratory Study ORNL/OEPA-11, "Structural and Leaching Aspects of Testing Fixated Solid Wastes Via the Toxicant Extraction Procedure." This paper will only address one aspect of each study to demonstrate the inappropriateness of the procedures.

The WES study placed stabilized wastes in columns, surrounded the waste with glass beads, and passed distilled water through the columns at a flow rate of 1×10^{-5} cm/sec. The column length was such that the water was in contact with the waste for approximately 106 days. The volume of water to waste was 0.5/1 as compared to 20/1 in the EP. The result was the washing of the surface of the waste and a determination of the rate of diffusion of the various constituents, if the stabilized waste were immersed in water. A few obscure sentences indicated that immersion in water was not the normal disposal method. But there was no emphasis on the fact that the Conversion Systems' process, and probably all of the other processes, is designed to minimize water contact. There was no effort made to evaluate the efficacy of the mechanisms utilized to reduce water contact, but only a highly unlikely worst case condition to simplify the task of the investigator. The results, therefore, have little or no value.

The Oak Ridge study attempted, at the direction of the US EPA, to evaluate the contamination potential of stabilized wastes if they were placed in a sanitary landfill. The study therefore attempted to quantify the destructive impact of waste compacted by crushing the waste before leaching. The Conversion Systems process is one of in-place compaction, which is not possible in a sanitary landfill. The EPA scenario therefore supposes the excavation of a stabilized landfill and redisposition in a sanitary fill. The extreme improbability of such a situation was never addressed. It is interesting to note that in addressing the Structural Integrity Procedure, the report states that the pulverized particles in the upper half of the cylinder used in the SIP dissipated the energy, and the following blows had little effect on the remainder of the cylinder. When the upper half of an SIP cylinder -- 1½ inches

is compared to a typical CSI landfill of 50 to 100 feet, it has little significance. Such misleading results, based on a misunderstanding of field conditions, are a disservice to the investigator and the stabilization process being evaluated.

Although this paper does not pretend to speak for all stabilization processes, it is clear that each process develops its own distinct properties in the wastes treated, and it is those properties that should be evaluated by whatever test protocols are applicable and not by some artificial procedure devised for the convenience of the laboratory technician. A description of the CSI process and the mechanisms utilized to prevent contaminant release will serve to illustrate why it is necessary to design an evaluation protocol for a specific process.

POZ-O-TEC PROCESS

The CSI process is based on the pozzolanic reaction that occurs when fly ash is mixed with lime and water. The resulting reactions are similar to those that occur in Portland cement concrete. The end product is a cementitious, monolith of high structural strength and low permeability. Despite the excellent physical properties of the stabilized wastes and the reduced solubility of many constituents, the Poz-O-Tec process is not intended to render the waste suitable for delisting. Rather the purpose is to develop physical properties that, when utilized in a proper setting, will prevent permeation to ground water, control runoff and protect the environment for an indefinite period. That proper setting is a structural landfill. The design and operation of the fill are therefore integral parts of the system. The testing and evaluation of a specimen of stabilized waste, in a manner that does not take into account the protective mechanisms of the fill itself, is highly inappropriate and meaningless. The entire system must be evaluated to determine the degree of protection afforded.

Structural Landfill Design

As the name implies, a structural landfill is constructed of material with physical properties sufficient to support the fill and provide good slope stability. The wastes must therefore be treated and stabilized. Any method of

stabilization will suffice provided it permits construction of the fill from the ground up and the stabilized material has an unconfined compressive strength, after curing, of >25 psi and a permeability of $<1 \times 10^{-5}$ cm/sec.

Construction

A structural fill, as shown in Figure 1, is built from the ground level up. It is therefore always higher than the surrounding area eliminating the possibility of run on. All surfaces are sloped promoting rapid runoff, which is collected in lined diversion ditches and directed to lined sedimentation ponds. The runoff can be treated as necessary or, depending on the process, used in the stabilization of other wastes, providing a closed loop system.

It is important to note that, due to the short contact time with the waste, the runoff is less contaminated and requires less treatment than leachate that has percolated down through a mass of waste and been in contact with the waste for many months. The greater the percentage of runoff, the lower the volume of leachate that could cause groundwater contamination.

Site

A structural fill should be built on the highest ground possible and at least 5 feet above the groundwater table. The site should be selected and prepared so as to prevent or minimize consolidation of the subsoil due to the weight of the fill.

Placement

Depending on the stabilization process, the treated waste should be placed in lifts of 2 feet and compacted immediately. The construction is a lamination, similar to plywood, with each layer sealing and protecting the layers below it. A minimum working area should be exposed at any one time and the side slopes should be capped, covered and seeded as construction progresses.

Liner and Cap

Since the land disposal regulations specify liner and cap designs, it is sufficient to point out that CSI complies with those requirements despite the use of stabilization. Stabilization serves as additional protection.

The Principle of Leachate Control in a Structural Landfill

It is axiomatic that there can be no more exfiltration from a landfill than there is infiltration. Contrary to a conventional landfill where the permeability of the liner is used to reduce exfiltration, the design and configuration of a structural fill combine with the low permeability of the stabilized waste to limit infiltration. The benefits of preventing infiltration are obvious; less water contacts the waste, less leachate is collected and treated and less leachate escapes to the groundwater.

Infiltration into a structural landfill is reduced or prevented through prevention of runon, promotion of runoff and the unavailability of water. Since the fill is built from ground level up, it is always higher than the surrounding area so runon is eliminated. Runoff is promoted by the proper sloping and contouring of the fill, during operations.

Due to the configuration of the fill water runs off immediately. Therefore, the only time there is water available for infiltration is during actual rainfall. That is the principal factor in the reduction of leachate generation. Permeation cannot occur when there is no water to permeate. The surface of a structural fill is dry 90% of the time. It is the duration of rainfall that is of concern, not the amount of rainfall. The permeability of the stabilized waste determines the amount of infiltration that can occur during any given period of time. By applying the time of recharge (duration of rainfall) to the permeability of the waste, we can determine the theoretical amount of infiltration that can occur in a year.

Figure 1 graphically demonstrates the following principles.

1. Because the fill is constructed from ground level up, there is no runon.

2. The sloped surfaces promote rapid runoff.
3. Runoff is collected and diverted to a collection pond.
4. The only time recharge (infiltration) can occur is during rainfall (10% of the time). At all other times, there is no water available to infiltrate.
5. Most of the water that does infiltrate is lost in evaporation which occurs 90% of the time.
6. The volume of leachate that can theoretically reach the groundwater is lower than from any other type of landfill.
7. With layered construction, each new layer seals those below it.

Evaporation

Rainfall varies in different parts of the country but the time that rain actually falls seldom exceeds 10% of the year. At other times (90% of the time), evaporation occurs. The permeability of the stabilized waste will determine how much water can penetrate in any given period. For example, a permeability of 1×10^{-5} cm/sec (worst case condition) is a rate of .014"/hour. The amount of rain that falls during an hour doesn't matter. The penetration can only be .014". Even after several days of rain the penetration will be less than one inch. Under the worst conditions, the moisture will be relatively close to the surface and available for evaporation. As the surface dries, capillary forces will cause entrapped moisture to move upward toward the drier material, making it more available for evaporation. The amount of evaporation that will occur can only be estimated, but even in humid climates it is anticipated that a minimum of 80% of the entrapped moisture will evaporate, leaving 20% as potential leachate.

Worst Case Leachate Generation

The following calculations for facilities, one in a humid area and one in a dry area, show the maximum volume of leachate under different climatic conditions. All conditions are the same except for the actual duration of rainfall as recorded by the National Climatic Center and the amount of evaporation.

Duration of rainfall (time of infiltration)	% of year
Humid Area	10%
Dry Area	4.5%
Evaporation of infiltrated water	
Humid Area	80% (40"/year)
Dry Area	90% (60"/year)

Permeability of stabilized waste 1×10^{-5} (worst case) = 120"/yr.

Calculated Leachate Generation

Through waste @ 1×10^{-5} cm/sec

Humid - 120"/year X .1 X (1-.8) = 2.4"/year

Dry - 120"/year X .045 X (1-.9) = .54"/year

With cap of 1×10^{-6} cm/sec

Humid - 12"/year X .1 X (1-.8) = .24"/year

Dry - 12"/year X .045 X (1-.9) = .054"/year

Liner and Leachate Collection System

A liner, with a measured permeability, acts as a flow control valve and reduces flow to groundwater to that permeability multiplied by the hydraulic gradient that is allowed to build up. In a conventional landfill, where leachate must be removed by pumping, the flow rate can be increased five to six times, due to the hydraulic head. That is not possible with a structural landfill that has a gravity feed leachate withdrawal system. There is never any driving force on the liner. The stabilized waste acts as a filter and prevents the build up of suspended solids in the leachate, eliminating the possibility of plugging. There are no pumps to fail and require maintenance during operation and after closure.

The efficiency of a liner/leachate collection system is determined by the permeability of the liner, the permeability of the drainage layer, the slope and the distance of travel to a collection pipe. Discounting the slope momentarily, if the flow of leachate to the liner is equal to or less than the permeability of the liner, the total flow will pass through the liner to groundwater. The flow through the liner at any given permeability and no head, remains constant. Therefore as the flow to the liner increases, the volume withdrawn by the

collection system and the efficiency increases correspondingly. For any given set of conditions, the efficiency of a liner can be increased by increasing the slope of the liner and shortening the distance to the collection pipes. For the purposes of this discussion, we have selected a slope of 5° and a maximum distance of 30.5 meters to a collection pipe. Many variations are possible, but here we are concerned with the principles of liner performance, not with details.

Liner Efficiency

Figure 2 (computer readout) shows the efficiency of two different liners (1×10^{-6} and 1×10^{-7}) based on Dr. Moore's formulae under the following conditions:

1. Slope 5%
2. Distance between drainpipes - 61M
3. Flow to liner: 1, 2, 3, 4 and 5 inches.

Applying those liner efficiencies to the flow rates calculated above, we find that the total flow, under worst case conditions, to be almost undetectable.

LEACHATE FLOW RATES - inches/year

	To Liner		Thru Liner @ 1×10^{-6}	
	Waste at 1×10^{-5}	Cap at 1×10^{-6}	Without Cap	With Cap
Humid Area	2.4	.24	.015	.00
Dry Area	.54	.054	.010	.00

Consolidation and Subsidence

Stabilized waste, after compaction and curing, will have an unconfined compressive strength ranging from 25 psi to 2-300 psi. The exceptional strength of the material, having been placed in 2 ft. lifts and compacted, will prevent any consolidation or subsidence of the waste. Subsidence of the subsoil is prevented by proper site selection and preparation. The elimination of subsidence significantly reduces the potential for cracking of the cap and final

cover. The inherent protection of the cap, coupled with a gravity feed leachate collection system, reduces the post closure maintenance to the possible erosion of the cover material. The elimination of potential post closure problems is one of the greatest benefits of the structural landfill.

Macroencapsulation

All wastes cannot be stabilized by any given process. Only those that can be properly stabilized i.e. unconfined compressive strength, after curing, of 25 psi and a permeability of 1×10^{-5} cm/sec, should be allowed as the structural element of a landfill. Other wastes with lesser stabilized properties or unstabilized can be safely and successfully macroencapsulated in a structural fill. The bridging capabilities as stabilized waste coupled with the fact that the confined strength of a material far surpasses the unconfined strength, makes macroencapsulation not only feasible but a desirable solution to the disposal of many wastes. Macroencapsulation should be addressed on a waste specific basis, but the principle and acceptability of macroencapsulation should be recognized and provided for in regulations covering structural landfills.

BENEFITS OF A STRUCTURAL LANDFILL

1. Low permeability of waste limits potential for infiltration.
2. Stabilization reduces solubility through complexing of certain constituents.
3. Sloping of fill promotes rapid runoff limiting contact time and infiltration.
4. All runoff is collected and a major portion can be used in stabilization process (depending on process) reducing potential discharge.
5. Construction above ground level prevents run on.
6. Waste encapsulated in cementitious matrix.
7. Liner/leachate collection systems captures all leachate.
8. Gravitational flow of leachate collection system eliminates maintenance during operation and post closure.
9. Filtration of leachate by stabilized waste prevents plugging of collection system.

10. No hydraulic head can develop on liner.
11. With layered construction (2 ft. lifts) each lift seals those below it. Permeability of entire fill is controlled by the lift with the lowest permeability.
12. No consolidation or subsidence which could cause cracking of the cap. Minimum post closure maintenance.

EVALUATION PHILOSOPHY

CSI's approach to performance testing has always been to select test procedures which simulate field conditions, as closely as possible. The testing program should evaluate process conditions and landfill conditions as well as the materials performance characteristics. The waste treatment and disposal industry is a relatively new field and very few standard test procedures exist. CSI has always tried to use existing test procedures, where applicable, in the evaluation of their systems. Where existing test procedures did not adequately represent field conditions, CSI modified these procedures or developed new ones. In the past few years, consulting firms and regulatory bodies have become more involved with the evaluation of treatment and disposal processes, and have tried to develop and standardize their own testing formats based solely on existing procedures, without having the detailed knowledge or experience that the disposal industry has acquired over the years.

The programs and procedures favored by the regulatory bodies and consulting firms are all directed towards standardization so as to fit all stabilization processes into one small, neat and tidy format. CSI believes that standardization is necessary to a point, and has worked very closely with EPA, the Department of the Army, ASTM, Consulting Firms and Universities, but believes that many treatment and disposal options available today are unique. Therefore, all of the various treatment and disposal processes cannot be categorized into a rigid testing format. Each treatment process must be tested on its own merits, under simulated field conditions.

CSI Testing Scheme

To evaluate our own process, we utilize a series of tests that we feel are most applicable. The scheme includes the analysis of the raw wastes,

preparation of stabilization mixes, testing of physical properties and leachate testing. This program is designed to ensure that the properties required to protect the environment will be developed when the waste is placed in the landfill.

Waste Analysis

The first step is the raw waste characterization. The waste is tested for concentration of specific constituents which are of interest and/or concern. Table 1 shows a typical testing scheme for a few high volume industrial wastes. Each waste stream is unique. Therefore, the raw waste characterization scheme must be flexible enough to evaluate the waste in sufficient detail, yet not burden the program with excessive , expensive and useless testing. Each of the parameters marked in Table 1 is run for a specific reason, in CSI's characterization scheme. A few examples of these are as follows: pH, Solids Content, and consistency are run to evaluate equipment compatibility; cyanide, ammonia-nitrogen, phenol, TOC, and GC are run in order to safeguard operating personnel; the remainder of the parameters listed in Table 1 are run for stabilization mix design development, and landfill placement/design development. Table 2 shows the test methods commonly used by CSI in their raw waste characterization. Over the 11 years CSI has been in existence, we have found that these test methods were the most expedient, accurate and economical methods to use.

We stated in the footnote in Table 2, most of the test procedures referenced are for the analysis of the specific parameters. Most of the modifications to the test procedures usually occur in the sample preparation prior to actually running the test.

Mix Determination

The next step is the stabilization and material performance characteristics. This step includes the design of the stabilization mix, strength development, permeability, and leachate testing. The design of the

stabilization mix includes reactant material selection, reactant material characterization, additive requirements for stabilization and a knowledge of the final material properties required to produce an environmentally sound material for disposal.

Sample preparation is one of the most critical features in the evaluation of materials performance characteristics. Test samples should be compacted at the same consistency, age, and moisture content as they would be compacted in the field. Plastic or fluid type materials (similar in consistency to concrete) should be cast in wax cardboard molds or other types of molds which retain their shape while preventing loss of moisture to the atmosphere. Damp, soil-like mixes should be compacted into steel molds using compaction techniques similar or representative to those to be used in the field. Standard laboratory compaction techniques exist for concrete (an example of a plastic type material) and soils (an example of a dryish type material). The compaction techniques listed in Table 3 are directly applicable to the Poz-O-Tec Process but would not be applicable to a treatment and disposal firm which pumps its stabilized material to a lagoon, where the only compaction that this material would receive is through gravity consolidation. Improper sample preparation is one of the major causes for unrealistic material performance data being generated.

Strength Determination

Strength development is typically evaluated in the CSI laboratory by unconfined compressive strength testing. Standard procedures exist for unconfined compressive strength testing (see Table 3) and these procedures are applicable to CSI stabilized material. Most of these tests are modifications of procedures used in evaluating soils, cement and concrete. The Poz-O-Tec process is chemical in nature (reaction mechanisms are similar but not identical to those seen in the hydration of cement) and are therefore, time and temperature dependent. Unconfined compressive strengths are usually run at 7 days at 100°F, 28 days at 73°F, 56 days at 50°F. Specimens are immersed in water for 4 hours prior to confined compressive strength testing to ensure that a chemical set has taken place. If, for any reason, a chemical set has not taken place, the specimen will deteriorate in the soak tank within 30 minutes after placement.

Permeability

Standard permeability test methods exist and these procedures can be directly applied to CSI stabilized material; however, CSI recommends the Army Corps of Engineers' Falling Head Permeability Test Method for its pozzolanic materials since the procedures and conditions listed in the test method are the most realistic of any permeability test method currently available. The theoretical conditions under which the test is run are:

1. Complete saturation (100%)
2. Constant recharge or supply of water
3. Hydraulic gradient of equal to or greater than 1
4. Continuous and static contact of the head of water with the material
5. Laminer flow through the test specimen

Laboratory determination of permeability is not truly representative of field conditions because:

1. In the design and operation of CSI's structural landfill, complete saturation will never occur, therefore, the hydraulic gradient is always less than one.
2. There is no constant recharge of water since the landfill is designed to avoid the pooling of precipitation and also eliminates run-on.
3. The stabilized material is not a soil for which the test was designed, but a cementitious material which changes with time (the pores inside of the matrix will seal themselves up as the cementitious crystalline structure continues to grow with time), and tends to decrease the degree of laminar flow and increase turbulent flow through the specimen.

Leaching Tests

CSI uses both the ASTM Method A and the EP. We find little difference in the results from each, and for our purposes either one is suitable. Despite the similarity in results, the EP does not accurately simulate field conditions. Some of the deviations are:

1. There is no way to correlate surface area to the volume of leaching medium

2. Crushing and screening of stabilized materials
3. Abrasion caused by stirring
4. Acidic medium
5. The small size of the specimens makes it difficult to evaluate a stabilized material containing large waste particles.

Runoff Test

CSI has developed what we believe is the best test procedure to evaluate a stabilized material in a structural landfill and we offer it for your consideration. We call it a Runoff Test because it simulates rainfall running across the surface of a landfill. One to two inches of clean sand are placed in the bottom of a specially constructed box. Stabilized material is placed, compacted and cured, on top of the sand. The box is tilted to the desired slope and water is sprayed on the upper end to simulate any amount and duration of rainfall. The water that flows across the surface is collected and recirculated to simulate a flow over a greater length of fill. Permeate, if any, is collected separately and analyzed in addition to the runoff. The flow can be stopped and the environment controlled to determine the effects of evaporation under any conditions. We believe that this test more accurately simulates what takes place in the field than any other test we know.

SUMMARY

In summary, we believe the evaluation of a stabilization process must be tailored to that specific process. The same procedure is not applicable to other processes and no evaluation is applicable to all processes. To attempt to develop a standard set of tests and standard values, to cover all processes, is a disservice to the supplier and to the public, because it will most certainly be prejudiced against some such processes.

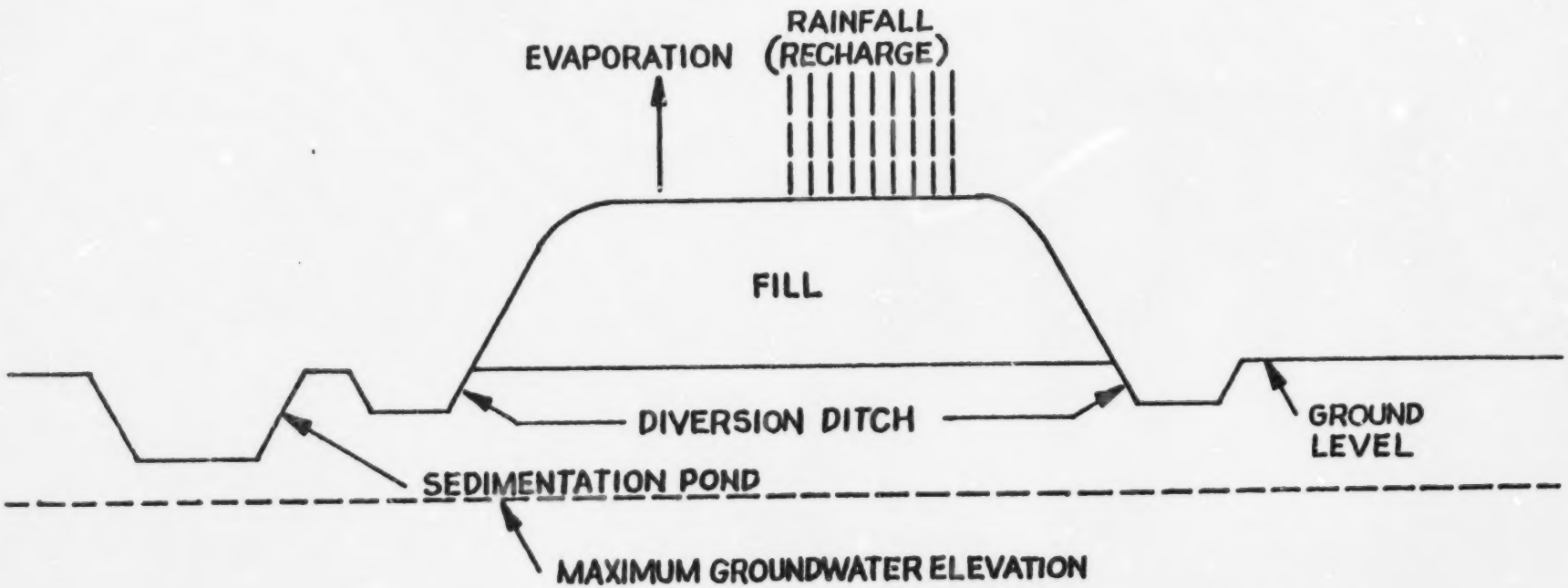
EVAPORATION
RAINFALL
(RECHARGE)
FILL
DIVERSION DITCH
GROUND
LEVEL
SEDIMENTATION POND
MAXIMUM GROUNDWATER ELEVATION

FIGURE 1

LINER/LEACHATE COLLECTION SYSTEM

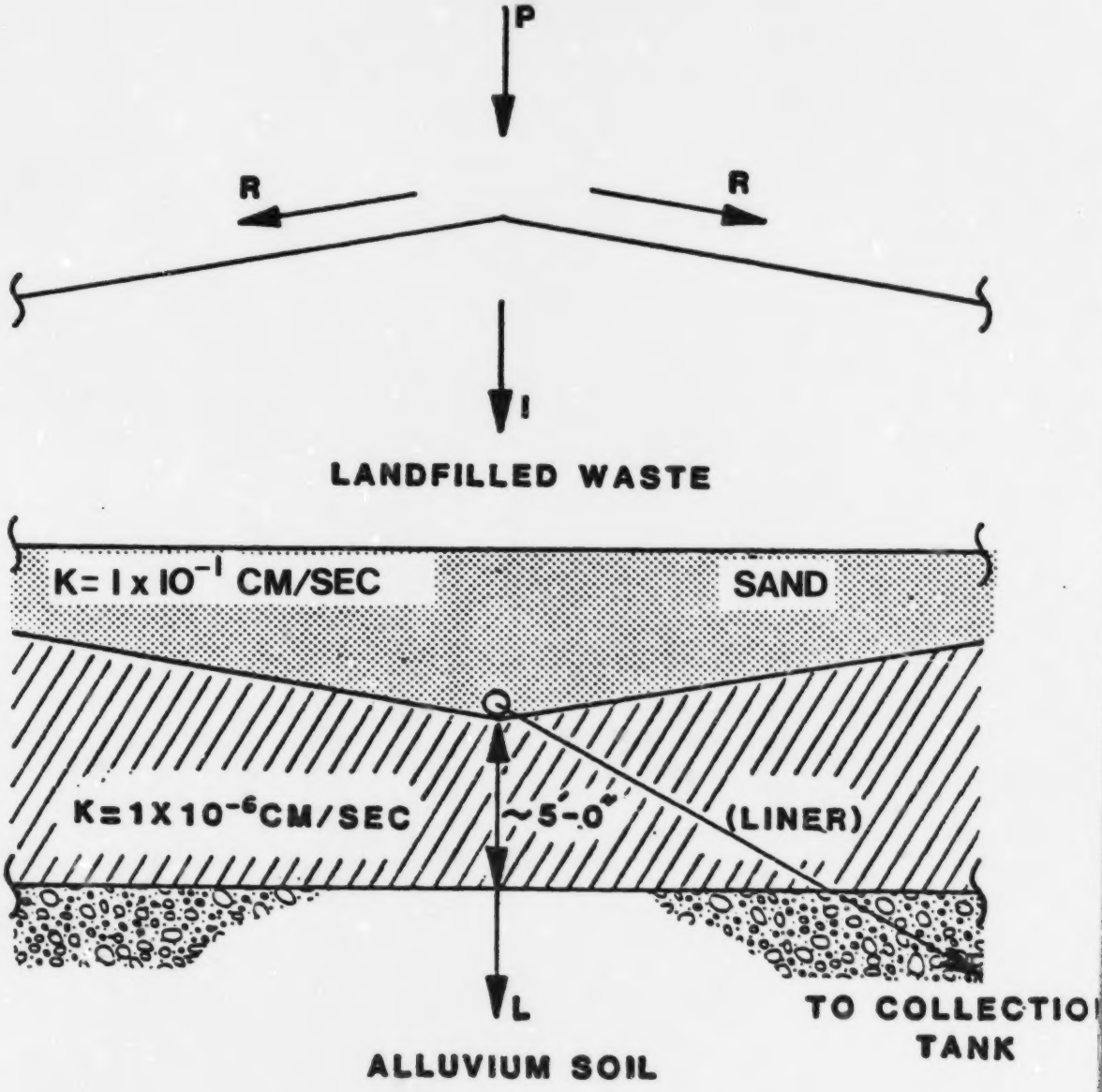

FIGURE 2

LANDFILL EFFICIENCY MODEL 3 - 29 - 1982 11 : 51

INPUT PARAMETERS -

MODULE 1	INITIAL	STEP	FINAL	ADD/MULT
KS1	1.0000E+00	0.0000E+00	1.0000E+00	0
KS2	1.0000E-07	1.0000E+01	1.0000E-06	1
D	61.00	.00	61.00	0
L	61.00	.00	61.00	0
ALPHA	2.86	.00	2.86	0
HO	2.54	2.54	12.70	0

MODULE	KS1	KS2	D	L	ALPHA	HO	EFFICIENCY	FINAL HO	OVERALL EFFICIENCY
1	1.0000E+00	1.0000E-07	61.00	61.00	2.86	2.54	.99875	.00	.9987
1	1.0000E+00	1.0000E-07	61.00	61.00	2.86	5.08	.99935	.00	.9993
1	1.0000E+00	1.0000E-07	61.00	61.00	2.86	7.62	.99955	.00	.9995
1	1.0000E+00	1.0000E-07	61.00	61.00	2.86	10.16	.99965	.00	.9996
1	1.0000E+00	1.0000E-07	61.00	61.00	2.86	12.70	.99971	.00	.9997
1	1.0000E+00	1.0000E-06	61.00	61.00	2.86	2.54	.98746	.03	.9875
1	1.0000E+00	1.0000E-06	61.00	61.00	2.86	5.08	.99348	.03	.9935
1	1.0000E+00	1.0000E-06	61.00	61.00	2.86	7.62	.99549	.03	.9955
1	1.0000E+00	1.0000E-06	61.00	61.00	2.86	10.16	.99649	.04	.9965
1	1.0000E+00	1.0000E-06	61.00	61.00	2.86	12.70	.99709	.04	.9971

FIGURE 3

TABLE 1
TYPICAL ANALYSES PERFORMED FOR RAW WASTE CHARACTERIZATION

	Steel Industry		Electro-plating Industry	Car Battery Manufacturing Industry	Petroleum Industry		Electronics Industry
Parameter	Electric Furnace Dusts	Milling Sludges	Metal Hydroxide Sludge	Waste Water Treatment Plant Sludge	API Separator Sludge	Tank Bottoms	Metal Hydroxide Sludges
pH	X	X	X	X	X	X	X
TOC	X	X	X		X	X	X
Phenol		X			X	X	X
Solids Content	X	X	X	X	X	X	X
Color/Consistency	X	X	X	X	X	X	X
CN			X				X
Oil & Grease	X	X	X	X	X	X	
$N\text{-}NH_3$			X		X	X	
As	X	X	X	X	X	X	X
Ag							X
Ba							
Cd	X	X	X	X	X	X	X
Cr_{+6}	X	X	X				X
Cr^{+6}	X	X	X	X	X	X	X
Cu			X	X			X
Hg	X	X	X	X	X	X	X
Mo							
Ni			X	X			
Pb	X	X	X	X	X	X	X
Se			X	X			X
Zn	X	X	X				X
GC		*			*	*	*
GC/MS		*			*	*	*
TOX		*			*	*	*

*Depends on character of the waste and degree of analysis required to treat, store and dispose in environmentally sound manner.

TABLE 2
TEST METHODS

	METHODS TYPICALLY USED			MODIFICATIONS MADE TO METHOD (If any)	REASONS FOR MODIFICATIONS
	Std. Methods	EPA	ASTM		
pH	423	9040	D1293		
TOC	505	9060	D2579		
Phenol	510A,B,C	420.1	D1783		
Solids Content	209	160.1-4	D1888	100° to 130°F	Greater than 130° drives off waters crystalization which lead to lower values
Color/Consistency					
CN	412A,B,C,D	9010	D2036		
Oil & Grease	503A,C	413.1			
$N\text{-}NH_3$	417A,B,D	350.1,2	D1426		
As	307A	3050-7060	D2972		
Ag	324A	3050-7760	D3866		
Ba	308	3050-7081	D3651		
Cd	310A	3050-7130	D3557		
Cr_{+6}	312A	3050-7190	D1687-D		
Cu	312B	3060	D1687		
Hg	313A	3050-7210	D1688-D		
Mo	320A	7470,7471	D3223		
Ni			D3372		
Pb	321A	3050-7520	D1886		
Se	316A	3050-7420	D3359		
Zn	323A	3050-7740	D3859		
GC	328A	3050-7950	D1691		
		801,etc. for Solid Waste 601 for Water			
GC/MS		801 etc. for Solid Waste 601 for Water			
TOX		9020	Proposed		

Notes:
- o Standard Methods for the Examination of Water and Waste Water, 15th Edition 1980
- o EPA Test Methods for Evaluating Solid Waste SW-646, 1980 and 1982
- o EPA Methods for Chemical Analysis of Water and Waste Water EPA 600 4-79
- o ASTM 1982 Annual Book of ASTM Standards Water Part 31
- o Methods are modified in sample preparation for specific types of wastes, as needed.

TABLE 3

TYPICAL TEST METHODS USED FOR MATERIAL PERFORMANCE TESTING

	TEST METHOD TYPICALLY USED	MAJOR MODIFICATIONS TO TEST METHODS USED	REASON FOR MAJOR MODIFICATIONS TO TEST METHODS
1. Test Specimen Preparation			
A. Plastic & Pourable Mixes	ASTM C-192	Specifically 3.1, 3.4, 3.5, 3.6, 3.7, 4.1, 4.4, 4.5, 6.3, 6.4	Method is for Concrete Cylinders
B. Damp Soil-Like Mixes	ASTM D698 or ASTM D-1557	Drying temperature is 100 to 130°F.	Method is for compaction of soils. At temperatures greater than 130° waters of crystalization can be lost.
2. Curing	ASTM C-192	Use, 100°, 73°, 50°. Samples are left in molds for duration of cure. Samples are not submerged in water.	Method is for concrete and does not give flexibility in curing temperatures.
3. Unconfined Compressive Strength			
A. Cast Cylinders	ASTM C-593, C-39	Drying temperature is 100 to 130°F. Samples soaked for 4 hours prior to testing.	At temperatures 130°, waters of crystalization can be lost. 4 hour soak ensures that a chemical set has occurred. C-39 i test for concrete cylinders.
B. Compacted Cylinders	ASTM C-593, C-39		
4. Permeability			
A. Falling Head Method	US Army Corps of Engineers Laboratory Soils Testing Manual EM-1110-2-1906 Section 7	Use hydraulic gradient of approximately 11/1 as standard.	Allows accurate measurement of water column drop for materials in 10^{-5}, 10^{-6}, 10^{-7}, 10^{-8} range.

TABLE 3
TYPICAL TEST METHODS USED FOR MATERIAL PERFORMANCE TESTING
(Cont'd)

	TEST METHOD TYPICALLY USED	MAJOR MODIFICATIONS TO TEST METHODS USED	REASON FOR MAJOR MODIFICATIONS TO TEST METHODS
5. Leachate Analysis	o Proposed ASTM A	Uses shake table instead of rotary extraction apparatus	Rotary extraction apparatus tumbles specimen in leaching container. This causes damage to test specimens and causes non-reproducible and erroneous results.
	o EPA-EP	Use only structural integrity tester procedure on stabilized materials.	Crushing defeats the purpose of stabilization.
	o Run Off Simulation (CSI Internal Procedure)		

SIMULATED FIELD LEACHING TEST FOR EVALUATION OF SURFACE RUNOFF FROM LAND DISPOSAL OF WASTE MATERIALS

Hugh Mullen
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MANUSCRIPT BY HUGH MULLEN

The following test procedure was developed to aid in the determination of the leaching potential of waste materials for land disposal. It is applicable to all solid and semi-solid materials. Note that care must be taken to utilize a specimen which represents as accurately as possible the condition of the material in the field.

This procedure is designed for rapid and accurate determination of leaching characteristics at minimum cost.

1. SCOPE

1.1 This method covers the determination of the surface runoff properties of soil or waste materials. The procedure is to establish representative values of the surface runoff, water absorption, and permeate properties of soils and waste materials as placed in embankments, landfills, or other suitable disposal sites.

2. FUNDAMENTAL TEST CONDITIONS

2.1 The following test conditions are prerequisites for suitable simulated field leaching of soil or waste material to simulate field conditions in as representative and uniform a manner as possible:

2.1.1 Continuity of water flow during test, with continuous recirculation of the resultant runoff,

2.1.2 Slope of top surface of material in test apparatus shall approximate that present in existing or anticipated field placement of the soil or waste material,

2.1.3 Water used in test shall be representative of rainfall at field site or Type II grade reagent water as defined by ASTM standard D1193,

2.1.4 Application rate in test shall be representative of rainfall rate at the field site, and

2.1.5 Placement of soil or waste material in apparatus shall approximate placement of the soil or waste material in the embankment, landfill, or other suitable disposal site.

3. APPARATUS

3.1 Test Box as shown in Fig. 1. This box shall be constructed of sheet metal and painted with waterproof corrosion/erosion resistant epoxy paint.

3.2 Peristaltic Circulation Pump equipped with pump head, rheostat-controller, and tygon tubing to attain a circulation rate of 20 gallons per hour. The pumping apparatus must be calibrated according to section 6.

3.3 Specimen Compaction Equipment - Manual 5.5 pound Rammer as defined in ASTM standard D698, section 2.2.1.

3.4 Scoop, with a capacity of 100g of soil or waste material.

3.5 Miscellaneous Apparatus - Clock, plastic buckets, vinyl-covered three pronged clamps, plastic spray bar as shown in Fig. 2, straightedge, 3/16 inch thick shim (at least 6 inches long), level, plastic sheeting, masking tape, graduated cylinder, mixing pan, etc.

3.6 Balance - A balance or scale of at least 100 pound capacity sensitive to 0.01 pound.

3.7 Membrane Filter Assembly - A borosilicate glass or stainless steel funnel with a flat, fritted base of the same material, and membrane filters (0.45-μm pore size) to fit. The filters shall be prepared in accordance with ASTM D1888, section 17.3.1.

3.8 Suction Flask, at least 500 ml capacity.

3.9 Vacuum Pump, minimum capacity of 1.67×10^{-5} min/atmospheric cm^3, attainable vacuum of 0.1 microns Hg.

3.10 Curing Chamber, capable of being held at 73.4°F (23°C) ±3°F (1.7°C) and 70% relative humidity, ±5%.

4. SAMPLE

4.1 From the material to be tested which is at the moisture content present or anticipated in the field, select a representative sample for testing equal to an amount approximately twice that required for filling the test box. The relative density and permeability coefficient of the material as placed or as anticipated in the field should be knwon. ASTM D2049 and D2434 give methods for determining relative density of cohesionless soils and permeability coefficient of granular soils.

5. PREPARATION OF SAMPLE

5.1 Take a small portion of the sample selected as prescribed in 4.1 for water content determinations according to ASTM standard D2216. In the case of waste materials containing components with water of hydration, the drying temperature should be modified to 100°F (37.8°C) ±3°F (1.7°C) to avoid removing any water of hydration during moisture content determinations.

5.2 Fill clean test box without slotted collar in place with dry standard sand as designated by ASTM method C778 to a depth of 2 inches. Weigh box with sand inside and record weight.

5.3 Place the soil or waste material in the box in uniform layers, being sure that all corners are filled, by one of the following procedures; note that the relative density of the material in the box should simulate the relative density of the material as placed in the field. Moisture content should be controlled as required to obtain expected field conditions.

5.3.1 For compacted soil or waste material, spread the soil or waste material from a scoop in the test box such that uniform layers are formed. Remix the soil or waste material in the mix pan for each successive layer to reduce segregation caused by taking material from the pan. Place the material to a depth of about 2 cm above the top of the test box. Following placement, carefully trim the soil or waste material even with the top of the test box by means of a straightedge, and weigh. Multiply the weight of the specimen and test box, minus the weight of the test box and sand, by .08; record the result as the wet unit weight, γm, in pounds per cubic foot of the test soil or waste material.

5.3.2 For material which will be compacted in the field, compact successive layers of soil or waste material to the desired relative density using the manual compaction device specified in 3.3. The slotted extension collar should be in place. Recommended procedure is to compact the prepared soil in the test box in 3 equal layers using 25 uniformly distributed blows from the rammer on each layer. During compaction the mold shall rest on a uniform, rigid foundation, such as provided by a cylinder or cube of concrete weighing not less than 200 pounds (90.7 kg.). Compact enough material so that the compacted soil or waste material extends about 2 cm above the slotted edge. Following compaction, remove the extension collar, carefully trim the compacted soil or waste material even with the top of the test box by means of a straightedge, and weigh. Multiply the weight of the compacted specimen and test box, minus the weight of the test box and sand, by .25; record the result as the wet unit weight, γm, in pounds per cubic foot of the compacted soil or waste material.

5.4 Preparation of Specimen for Test

5.4.1 Carefully insert the 3/16 inch shim under the back legs of the test box. This procedure yields a material surface with a slope from back to front of 1.5%, simulating expected landfill construction practice. If other slopes are desired, select board thickness accordingly.

5.4.2 Measure and record weight of filled test box. Compute and record the initial sample weight of the test specimen.

6. PUMP CALIBRATION

6.1 Assemble peristaltic pump, pump head, and rheostat-controller with tygon tubing.

6.2 Place 3 gallons of water into a clear plastic bucket. Place the pump inlet side tubing in the water.

6.3 Place pump outlet side tubing into an empty plastic bucket marked at the one gallon level.

6.4 Set rheostat-controller to #1 and run pump until 1 gallon of water has been pumped into the initially empty bucket. Measure and record time for pumping this gallon of water. Compute and record pump output flow rate, in gallons per hour, at a rheostat-controller setting of #1.

6.5 Repeat 6.4 for each speed setting of the rheostat-controller.

6.6 Plot rheostat-controller speed setting versus pump outlet flow rate.

6.6.1 Once calibration according to 6.1 through 6.6 is complete, the pump, pump head, and rheostat-controller used in calibration must be used as a set in section 1.

7. PROCEDURE

7.1 Attach clean plastic spray bar as per 3.5 across the back of the test box with three pronged clamps and join it to the outlet side of a calibrated peristaltic pump/pumphead assembly.

7.2 Measure one gallon of water specific for the proposed field site, representative of the average rainfall, or Type II grade reagent water as per 2.1.3 Place measured water in a clean plastic bucket placed under the inclined drain spout. Place the pump inlet side tubing into the water. Set the calibrated pump controller rheostat for a flow rate of 20 gallons per hour.

7.2.1 The flow rate of 20 gallons per hour prescribed in 7.2 corresponds to the following linear feet of surface runoff at the specified rainfall rates:

Rainfall (in/hr)	Linear Feet of Runoff
1/4	255
1/2	130
1	65
2	35

As desired this test may be run simulating other conditions to conform with the rainfall rate and dimensions operative at a particular field site. Figure 3 relates linear feet of surface runoff to flow rate of recirculated runoff in the surface runoff test at constant rainfall rates ranging from ¼ in/hr to 2 in/hr. As described, this method uses a .5 $ft.^2$ exposed superficial sample surface area to simulate the runoff from 65 linear ft. The test may also be run using a true 1" rainfall over the exposed area. In that case the procedure would only determine the runoff contribution from .5 $ft.^2$ exposed superficial surface area.

7.3 Start pump and recycle the one gallon of water for one hour. Collect any seepage or permeate from the bottom drain of the test box. Stop pump after one hour.

7.4 Stir the circulated runoff water to resuspend any solids. Analyze a portion of runoff water for particulate and dissolved matter in water in accordance with ASTM D1888. Vacuum filter the remaining runoff using prepared plain white membrane filter discs of the prescribed pore size. Where sample bottles are employed for collection of the filtrate, the entire contents of a sample bottle should be filtered.

7.5 Measure and record the volume of seepage/permeate in ml. Stir the seepage/permeate to resuspend any solids. Analyze a portion of seepage permeate for particulate and dissolved matter in accordance with ASTM D1888. Vacuum filter remaining seepage/permeate as in 7.4.

7.6 Weigh box. Calculate the record percentage of water absorption of the test specimen.

7.7 If runoff or seepage/permeate properties are desired at additional sample ages or after special curing, prepare the test box for curing according to the following procedure.

7.7.1 Place sample in curing chamber as specified in 3.10. These conditions may be modified to simulate the climatological conditions to which the soil or waste material will be exposed.

7.7.2 Cure sample as in 7.7.1 for 7, 14, 21 and 28 days, repeating step 7.1 through 7.6 and 7.8 after each 7 day period. These curing times may be modified to simulate the climatological conditions to which the soil or waste material will be exposed. Under such conditions the curing time shall be a minimum of 7 days and a maximum of 14 days.

7.7.3 After the final cure and leaching period, the soil or waste material in the test box shall be sampled at various depths for moisture determinations according to ASTM standard D2216.

7.8 Chemically analyze all runoff water and seepage/permeate according to the schedule outlined in Table I. This schedule represents a recommended minimum analysis program. Depending on test requirements and applicable regulations, component analyses should be performed according to the appropriate ASTM standard methods. Record all analysis results, expressing pH in standard pH units and all other parameters in mg/l of the specified constituent. Phenolphthalein alkalinity and total alkalinity shall be expressed as meq/l and hardness shall be expressed as epm, in accordance with the ASTM standards indicated in Table I.

7.9 This test box and method of sample preparation can also be used to evaluate the effect of ground water contact on the bottom of the sample.

7.9.1 Attach a clear plastic vertical standpipe to the bottom drain of the prepared test box. Silicone sealant or similar material should be used to insure a leak free join. Open drain valve on front of box. Slowly pressure saturate the sand in the bottom of the test box through the standpipe using water specific for the proposed field site of Type II grade reagent water as defined by ASTM standard D1193. When water is flowing out of the drain valve at a constant rate equal to the input rate, close drain valve to maintain saturation.

7.9.2 Remove pressure head from standpipe. Adjust water level in standpipe so that it simulates the ground water level expected at the test site relative to the sample bottom.

7.9.3 Allow water to contact soil or waste material for 7 days. Contact time may also be adjusted to suit expected field conditions. Any such modified contact time should be based on the design contact time expected in the field, based on rate of ground water flow at the site and exposed sample area in the

test box. Monitor and record daily changes in the standpipe water level during the contact time. After each day's monitoring, the water level should be adjusted to the initial level determined in 7.9.2.

7.9.4 After 7 days have elapsed, drain out the contact water and analyze for desired chemical constituents. Recommended minimum procedure is outlined in item 7.8.

7.9.5 This test can be modified to suit a number of conditions. For example, the test can be run on as-received samples and/or samples cured for various times, as desired. Another alternative is to repeat exposure to a cured sample at regular intervals. Each of these alternatives may be analyzed using approximations and appropriate diffusion equations to give some idea of the rate of mass transport away from the soil or waste material.

8. REPORT

8.1 The report of simulated field leachate test shall include the following information:

8.1.1 Project, dates, sample number, location, and other pertinent information,

8.1.2 Dry unit weight, initial void ratio, and relative density asplaced,

8.1.3 A statement of any departures from standard test conditions, so the results can be evaluated and used,

8.1.4 Complete test data including volume of seepage/permeate, % water absorption of the test specimen, analysis of the runoff water, the seepage/permeate.

TABLE I

IUCS SIMULATED FIELD LEACHING TEST

RUNOFF WATER AND SEEPAGE/PERMEATE

CHEMICAL ANALYSIS SCHEDULE

PH (ASTM D1293)	X
Phenolphthalein Alkalinity (ASTM D1067)	X
Total Alkalinity (ASTM D1067)	X
Hardness (ASTM D1126)	X
Sulfite (ASTM D1339)	X
Sulfate (ASTM D516)	X
Chloride (ASTM D512)	X
Dissolved Matter (ASTM D1888)	X
Particulate Matter (ASTM D1888)	X
Arsenic (ASTM D2972)	X
Calcium (ASTM D2576, D511, D1126)	X
Cadmium (ASTM D2576)	X
Chromium (ASTM D1687)	X
Copper (ASTM D1688, D2576)	X
Iron (ASTM D1068, D2576)	X
Mercury (ASTM D3223)	X
Manganese (ASTM58, D2576)	X
Sodium (ASTM D1428)	X
Lead (ASTM D2576)	X
Zinc (ASTM D1691, D2576)	X

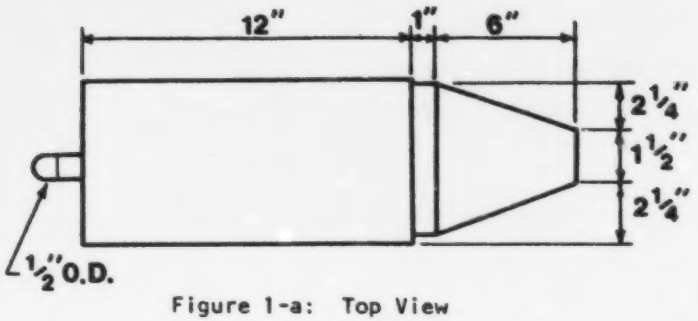


Figure 1-a: Top View

Slotted Join (See Figure 1-d: Top View

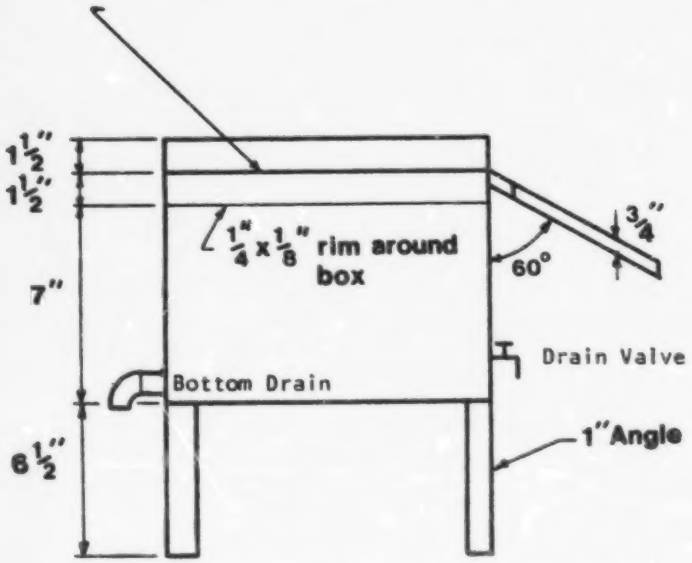


Figure 1-c: Side View

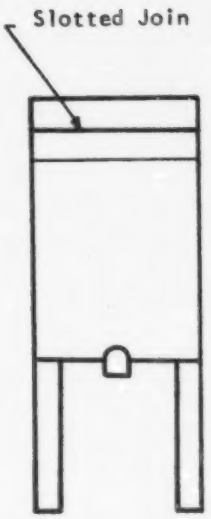


Figure 1-b: Back View

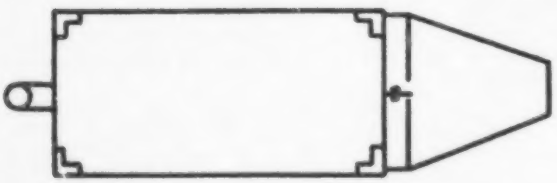


Figure 1-e: Bottom View

FIGURE 1. SIMULATED FIELD LEACHING TEST BOX

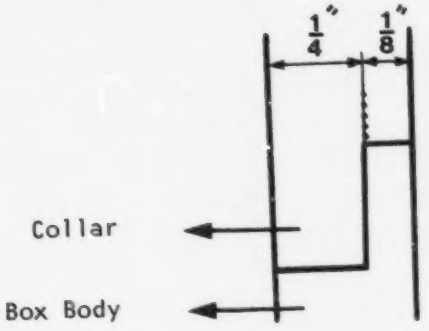
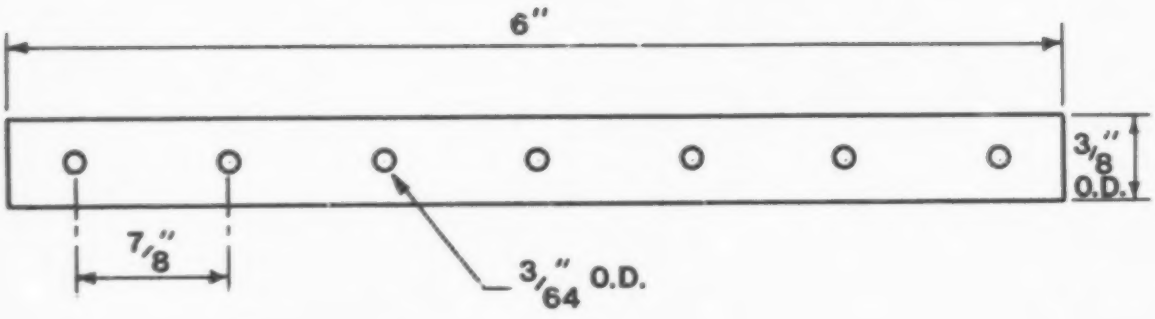


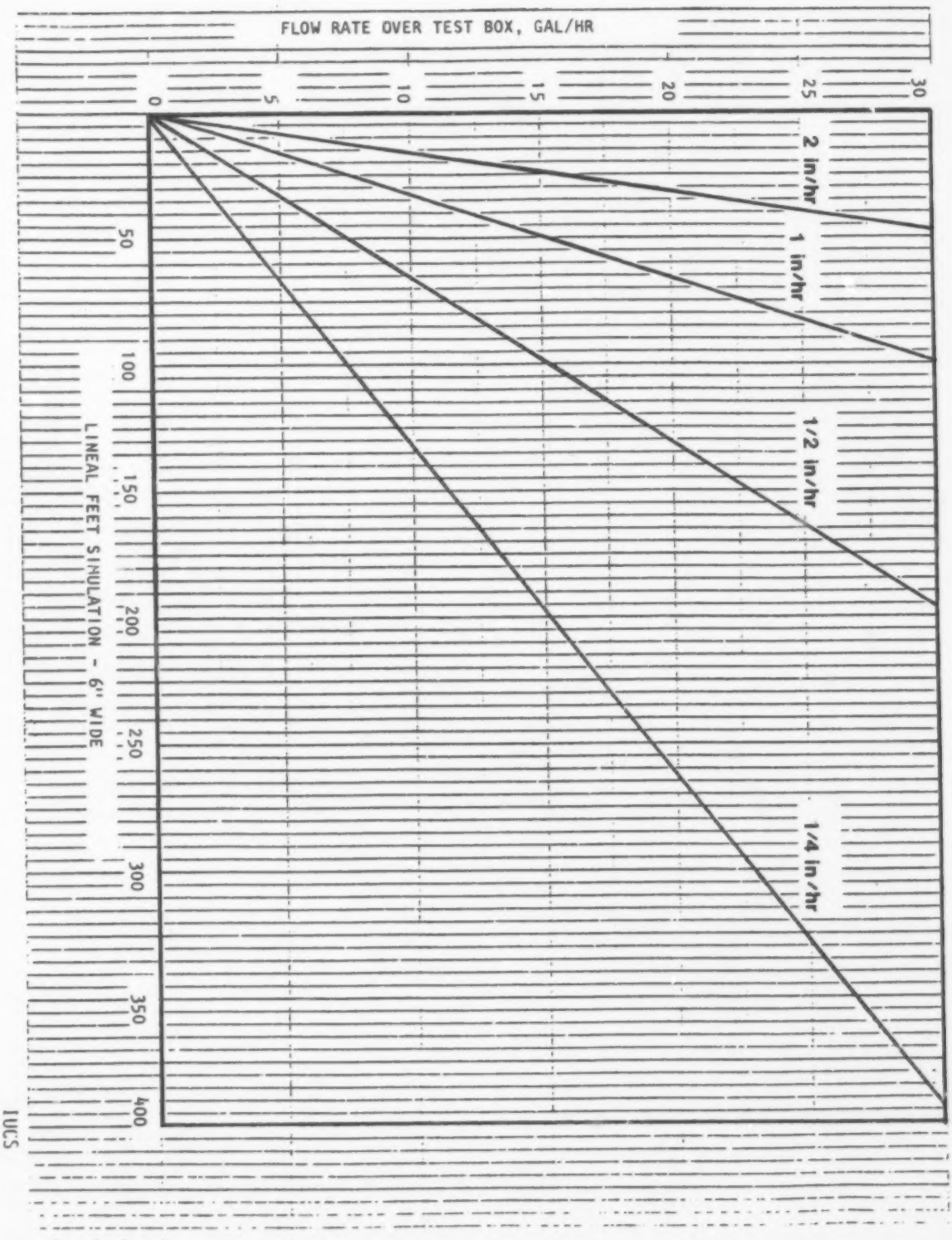
FIGURE 1-d. SLOTTED JOIN

Fabrication Notes:
1) Box body and legs constructed of 3/16" thick steel sheet or equivalent.
2) Front sloping extension constructed of 1/8" thick steel sheet or equivalent, troughed to yield 3/4" high sides.
3) All indicated dimensions are from metal edge to metal edge.
4) All box surfaces should be painted with waterproof corrosion/erosion resistant epoxy paint.



Bar is constructed of plastic or tygon tubing of specified OD. One row of holes of the specified size is drilled into the tubing.

FIGURE 2. SIMULATED FIELD LEACHING APPARATUS SPRAY BAR


FLOW RATE OVER TEST BOX, GAL/HR
0
5
10
15
20
25
30
2 in/hr
1 in/hr
1/2 in/hr
1/4 in/hr
50
100
150
200
250
300
350
400
LINEAL FEET SIMULATION - 6" WIDE
IUCS

DISCUSSION

P. Cote - I guess your overall approach to landfilling solidified waste, by siting it over the ground and all that, constitutes maybe a second or third barrier or third level of protection for the ground water. But I don't think it prevents us to evaluate the solidified waste per se, how well the process did in solubilizing and reducing the mobility of contaminants. I guess it's the first cut. You do that and then you have a second level of protection which might be a clay liner.

H. Mullen - If you continue with your analysis, and don't stop it just running a leaching test and saying this is 6 parts per million, or .06 parts per million, or something, therefore it's unexceptable, yes. Because that will occur only under those leaching tests, the conditions of the leaching tests. The test program that they ran out at the core of engineers, which I did not talk about and am now talking about: They placed the material in columns and the water was in there, the water was in contact with it for 106 days, I think; it simulated permeability 10^{-5}. Well, all it did was determine the diffusivity of the material, if you put it in a bath of water. Well, we don't put our material in a bath of water and we do everything possible to prevent it. We use the required liners, obviously, under the landfill because it's required by the regulations, and also it is politically and psychologically unacceptable not to, even if they didn't require to, we couldn't get the local people to accept it if we didn't. So you have the novel protection of the EPA regulation liner plus stabilized material.

P. Cote - Also, you avoid the problems of leaching or contact with the ground water at short term, but you get into other problems of weathering, maybe, by having the waste above ground.

H. Mullen - You could say that's a trade off but I don't believe so because the landfill has to be capped just as any other landfill and all other landfills, even though they're cell type, they come above ground. They are capped with synthetic and clay and seated over burden. The benefit that you do have is, if there is any problem you can see it and you can get at it. If you have a liner that's 50 feet down and something ruptures, without exuming the whole waste, all of the waste there's no way you can cure it.

R. Gotts - I would think that you must disagree substantially with Dave Friedman's agency's philosphy that the test protocol should be developed. I hope I'm not misquoting him too far to assume mismanagement of the waste.

H. Mullen - Well, yes. David has a different mission in life. He is trying to prevent the incorrect placement. Now if you want to evaluate stabilization processes, you've got to evaluate them in the proper settings and for us the proper setting is a structural landfill. For Stablex its something else for Chemfix its something else, but you've got to evaluate them in that setting because that's the way their going to be applied in the field.

R. Gotts - Just one other quick question. As a regulator, my concern would be with your submission there. While it may work extremely well and do everything you say, and more, for that first 30, 40 or fifty years, the material that's encapsulated may be just as hazardous if mismanaged subsequently. As a regulator looking down the road, a hundred years or so, I have less assurance in a facility that seems to depend on continued maintenance of the engineered features i.e. leachate collection treatment, and so on, when I have to look at that type of time span. Have you got any comment on how you'd protect future populations against those problems.

H. Mullen - At any landfill you have the same problem. You still have to maintain it, you still have to withdraw leachate or do something to protect it. We believe that this is a much simpler type of landfill to maintain and protect. And if it is exposed you have a monolithic mass there, that has to erode, if you will, and will do so very slowly.

D. Friedman - I think, the thing we have to keep in mind is, really we have two areas, as I tried to point out this morning, where we're concerned about testing. One is from the standpoint: does the waste still need to have professional controlled management? And that's what things like the EP are all about. We are concerned about: do we want to make sure it's properly managed? And I think what Hugh is talking about is the other factor. Once you've decided, for example, for whatever reason, the waste needs controlled management: how do we design a facility or evaluate a facility design, might be a better term, to know whether that facility design is appropriate for that

waste. I think that's where the test that Hugh was talking about will fall into, in evaluating the engineering design for a particular waste in a particular situation. The big problem that we've had is, as Hugh indicated, tests that the EPA has designed for that first purpose are being used by people for the second purpose. Then people complain it's not the proper test. Can't argue with that because it wasn't designed for that purpose. But we don't have tests developed yet and that's partly our fault and partly just everybody's fault. There is a limit to what we can do all at once and I think that's one area, as we pointed out, in quality control, and in other aspects, in developing some test methods for evaluating the engineering design.

H. Mullen - And that's why I believe that if this kind of dialog continues and industry works with the regulatory people we will get beyond this initial characterization of waste and the true evaluation of what we can do in the field.

SOLIDIFICATION OF INORGANIC WASTE

Mr. Pierre Grenier
Stablex Canada Inc.

MANUSCRIPT BY P. GRENIER

EXECUTIVE SUMMARY

This paper discusses the Stablex's process for the treatment and solidification of inorganic waste.

Process flow and control procedures are described with emphasis on those elements which serve to protect the environment and guarantee the quality of the final solidified product.

Particular attention is paid to quality control and the measures utilized by Stablex to determine the effectiveness of the process. A mention is made of those wastes which are good candidates for this waste treatment and those that present problems and chemical pretreatment.

A discussion on the limitations and usefulness of existing standard or recognized tests to measure immediate and long term security of solidified waste.

Ideas will be presented to measure the solidified material and formulate standards for delisting, recycling and disposal.

INTRODUCTION

The waste management industry exists today because the growth and industrialization of our society over the last century, and particularly in the last few decades, has generated increasingly large volumes and varieties of waste.

The waste management industry also exists because the governments have decided that in the public interest, the disposal of these waste had to be controlled and severely regulated. The technologies exist or can be readily developed to practically eliminate the rejection of hazardous waste in the environment. Most of the waste can be adequately destroyed or detoxified if

there is a political will to do so. There is an immediate cost to the implementation of a sound technically based waste management industry and a long term cost in not implementing it now.

The degree of elimination and the future quality of our life is directly related to the legislations that are adopted, the regulations and standards that are enforced, the treatment systems that are chosen and the control mechanisms that are put in place.

In 1978, after assessing the existing legislation in Canada, Stablex foresaw that the fixation/solidification technology could be the right answer to the concerns of Canadians to resolve the problems of environmental pollution from inorganic hazardous waste. They offered then the Sealosafe process developed in U.K. in the early 70's by one of the parent companies. Since June 1983, Stablex Canada operates a treatment centre of inorganic waste in Blainville, Quebec.

THE SEALOSAFE PROCESS

Most compounds and elements, essentially heavy metals, classified as hazardous inorganic waste were initially water insoluble, environmentally inert natural ores. However, in the process of extracting and transforming these ores, man has made them water soluble and thereby accessible and reactive with living organisms. Stablex through further physical and chemical changes converts these compounds and elements into a synthetic, water insoluble solid material that behaves like the original natural ore.

In order to accomplish these transformations, the Sealosafe process uses raw materials such as fly ash and cement, that results in a product with a durability and structural integrity similar to a natural stone.

The process, as applied in Blainville, is described presently and graphically presented in figure 1.

WASTE RECEPTION AND STORAGE

Incoming waste products are recorded, weighted and sampled. They are segregrated according to type; that is liquid, sludge or solid. Separate areas are provided for acid, alkaline, cyanide and chrome waste. The entire reception area is paved, curved and graded to contain any spilled waste. Run-off from various unloading areas is directed to a variety of sump-pumps, and the material collected is introduced into the process to make certain that no waste products are discharged into the environment. As an added protection, all precipitation falling on the plant site is collected by a series of french drains and sent to the plant where it is tested and treated if necessary.

PRE-TREATMENT

The combination of the chemical and physical reactions taking place at the Stablex, Blainville plant, are complex and numerous. Depending upon the type of waste, an appropriate chemical pre-treatment may be necessary. For example: cyanide is oxidized into cyanate with selected reagents, and hexavalent chrome is reduced to the trivalent state. Neutralization agents are selected to yield insoluble salts. The objective of this pre-treatment stage is to convert the elements or compounds into a more stable less reactive form prior to submitting them to the process we call stock preparation.

STOCK PREPARATION

Following pre-treatment a variety of waste products are combined to form the optimum mix for the fixation reaction. Total solid content is adjusted to take maximum advantage of the solidification of the waste slurry. This process takes place in reactors that are situated over weigh-scales so that the waste mix can be carefully controlled. After the reaction takes place quality assurance testing is performed to make sure that each batch of material is within specification.

FIXATION/SOLIDIFICATION

The stock is now fed into a mixing tower where it is combined with the final reagents. For this final step of the process, Stablex uses mainly

portland cement in combination with other pozzolanic materials such as fly ash. The additives and reactions that are taking place throughout the various steps of the process up to the solidification in the placement site have the following functions:

A) Neutralization

One of the most aggressive characteristics of inorganic waste is their pH level. The first and simplest treatment that is applied consists in the neutralization to a more satisfactory pH level.

B) Precipitation

The lime, cement and pozzolanic additives will essentially supply calcium which will precipitate many of the anions present in the industrial waste, such as phosphates, sulphates, arsenates, borates, fluorides, zincates, chromates, leadates, tungstates. The calcium salts that are formed are minutely soluble. For some elements however, specific reagents will be required to form a precipitate. They will be identified and added at the appropriate step.

C) Hydratation (sic)

The hydratation of the cement is a well known phenomena that produces the solidification of a fluid mass into a solid offering strong mechanical resistance, structural integrity and high degree of impermeability.

D) Absorption

One gram of anhydrous cement having typically a specific surface area of 1 m^2 will generate a hydrated paste having a specific area 100 times larger. In this hydration process the cement, and to some extent the other selected reagents, will develop physical and chemical absorption phenomena which are very useful in the treatment of waste to reduce the mobility and leachate of some elements.

E) Complexation

The hydrated cement is characterized by a high pH in a range of 12 to 13. Under these conditions the aluminate ion forms numerous complexes of which the trisulfoaluminate is the most useful. Many anions, other than sulfates, will also form aluminate complexes. For example, Cl, Br, I, NO_3, NO_2. MnO_4, CrO_4 will form aluminate complexes where calcium salts are practically insoluble. This complexing function adds to the precipitation effect mentioned earlier and reduces solubilisation of many of the toxic ions.

PLACEMENT OF SOLIDIFIED MATERIAL

The cement slurry emanating from the mixing tower is transported to a placement site. It is hoped that within a short period of time this material will find some practical use rather than be placed in the expensive placement sites as presently required by our operating permit.

MATERIAL ACCEPTANCE AND CONTROL PROCEDURES

Similar to most chemical plants, Stablex is highly concerned about proper identification of incoming materials, process control safety, and quality assurance. The following steps assure that we maintain a rigid control over the process:

A) Waste screening

A sample of the material to be treated is forwarded to Stablex's laboratories. Working closely with the generator, Stablex then determines the precise nature of the sample, submitting it to complete and scrupuleous analyses. The presence of at least 26 potential elements, including cadmium, chrome, nickel and lead is detected. In all a total of 17 physical-chemical test such as pH level radio -activity, density, cyanides, sulfates, etc. are conducted on the sample.

The number and proportion of additives required to render the sample harmless is determined. The laboratory, subsequently simulates factory conditions in converting the sample into Stablex. After Stablex is produced, it is subjected to leaching tests. Stablex also conducts test on permeability, and compressive strength. Only upon successful completion of the above tests is an agreement to accept the waste completed, delivery scheduled, and a price set.

B) Waste reception

Wastes are delivered to our facility in tank trucks, dump trucks, and drum carrier trucks. On entering the facility, the vehicle passes over a weigh scale and subsequently to a sampling station. A sample is taken and analyzed immediately to confirm the waste delivered corresponds to the waste characterized earlier. Once this is confirmed the vehicle is directed to the appropriate unloading station.

C) Quality control

Those wastes, which must be pretreated, are analyzed to assure that the treatment processes are complete. Continuing surveillance is a crucial part of the process. At several stages during the treatment, chemical checks are carried out on the material being produced to make sure it corresponds to the Stablex norms.

Although the Stablex material has been proven to be safe, it will be monitored after it has been produced, to ensure that the placement area remains free of contamination. Monitoring wells assure that no part of the Sealosafe process affects ground water adversely. Results from these monitoring wells are submitted to the Ministry of the Environment who also have access to Stablex records.

THE STABLEX PRODUCT

The toxicity of an element is dependent on the damage it can cause to living organisms when absorbed in quantities exceeding some critical level. Within those limits some of these same elements are useful and even essential to life.

A compound or element is a hazardous waste when it exists in a form that makes it readily available in harmful quantities. When properly treated, it may no longer represent a hazard.

Therefore, the most important criteria determining whether the wastes have been rendered non-hazardous in the Stablex process is by insuring that the toxicants have been trapped in the fixation/solidification product in a manner which does not allow then to re-enter the environment in a quantity that will cause harm.

Stablex relies on three principal criteria to evaluate the effectiveness of the solidified product to protect the environment. They are:

-Permeability
-Leaching
-Compressive strength

Permeability

The degree of water pollution that occurs when industrial waste is deposited into a landfill site is strongly influenced by a parameter known as, permeability; this indicates the rate at which water passes through a material. The lower the permeability the more likely it is that water will run-off the surface of the waste, rather than pass through it, thus greatly reducing the possibility of water contamination.

Leaching

Despite the impervious nature of the Stablex product, it is conceivable that over a long period of time the polymer will be brought into intimate contact with natural waters and acid rains. The effect of repeated freeze-thaw cycles over time could cause some physical product break-down. It is therefore desirable to ensure that pollutants would not leach from the product even under drastic circumstances where the product would be fractured into small pieces. To simulate these types of occurance, Stablex performs a leaching test using a method which requires the polymer to be ground down to a fine powder and then totally immersed in distilled water that has been acidified to a level of pH 5.

This test is also conducted on waste that have been mixed with the solidification reagents but which have not as yet cured. The principle here is that if the leachate test is satisfactory for this more severe one, then the cured material will be even better.

It can be seen by the results obtained in the leaching tests that the Stablex polymer controls leaching to such a degree that pollution of ground waters is no longer a risk.

Compressive strength

Disposal to a landfill site of industrial sludges and liquids usually prevents the subsequent utilization of the site for development purposes. The land is frequently sterilized, or at best covered over and returned to wild vegetation.

The Stablex slurry is ideally suitable for land reclamation. The slurry is free-flowing and self-compacting, it will settle without voids. As it hardens to a rock-like solid, it develops considerable strength.

Compressive strength can be easily adjusted according to the applications and will increase with time, generally reaching a constant value after six (6) months. It must be also noted that the compressive strength of the product could vary depending upon the waste mix being treated. The obvious

conclusion is that the compressive strength coupled with the nonleaching and permeability characteristics show that the filling of disused quarries, with the Stablex product is a satisfactory method of recovering otherwise derelict land for future development.

EVALUATION OF LONG TERM SECURITY

Stablex believes that the process is most efficient when dealing with a large variety of inorganic waste products and that the resulting product is safe, environmently inert and susceptible of finding commercial application.

Today this process represents the ultimate treatment for the disposal of inorganic waste. However the assessment of its performance and long term security represents a problem because the current regulations and environmental standards are not designed to deal with that kind of treatment. Therefore, the analytical procedures and standards would need revision to properly measure the potential performance of the solidification process.

The waste disposal regulations seem to be centered around the leachate characteristics of a sludge and the impermeability of a landfill. The Sealosafe process is one step further since both the low leachability of the waste and the permeability are integrated into the final product.

In measuring Stablex's performance one has to look at leachability of chemically bound material. This test is well done by the current EPA acid measurement test. This test however only indicates the level of equilibrium that will be reached if the product is kept in stagnant acidic water. If continuously exposed to running water, it is understood that the equilibrium will be continually displaced and that eventually all materials will leach out.

This test is an indication of how long it will take for a sludge in contact with running acidic water to release the toxic elements.

A test to measure the mobility of the elements within the solidified product is needed. The mobility or immobility of a toxic element in the solid matrix is an important factor that will prevent the leaching of an element or at least delay considerably the displacement of the solubilisation equilibrium when

exposed to water. The mobility of the element is a major factor in assessing the long term security of the product. The current leaching test that is performed does not measure this characteristic because it calls for destruction of the macro matrix and maximization of the surface of contact. That is fine, informative but incomplete.

The long term security of solidified waste is also assured by the low permeability of the final product. The regulations are centered around the permeability of a landfill site for the long term security of the environment. The solidified material bears in itself this protective characteristic. Again, the proper measuring tools and agreement on those tools have to be finalized.

Finally, another important characteristic of solidified waste is its mechanical resistance, the structural integrity of the material which facilitates the recovery of any land used for disposal.

CLOSING REMARKS

We believe at Stablex that solidification represents the most desirable solution to inorganic waste disposal. It is also a method that is not necessarily more expensive than secure landfill and perpetual care of non-treated toxic waste while assuring a better protection of the environment.

We are recommending that the regulatory authorities look at a set of standards and analytical procedures that will address the combined characteristics of a solidified waste that is leachability, mobility, permeability and structural integrity. Any product that will fail to meet one of the criteria low leachate, low mobility, low permeability, structural integrity and mechanical resistance, will require a containment that would supplement its failure.

The product that would meet all of the standards, should be considered as any natural ore that contains the same type of elements and should be delisted and made available for commercial applications.

TABLE I

TYPICAL VALUES OF COEFFICIENT
OF PERMEABILITY (cm/sec.)

CLEAN GRAVEL	1.0 and greater
CLEAN COARSE SAND	1.0 to 0.01
SAND MIXTURES	0.01 to 0.005
FINE SAND	0.005 to 0.001
SILTY SAND	0.002 to 0.0001
SILT	0.0005 to 0.00001
CLAY	0.000001 and smaller
TYPICAL CONCRETE	0.000001
STABLEX PRODUCT	0.0000001 to 0.0000002

TABLE II

HAZARDOUS WASTE TREATED MAY CONTAIN

Aluminium	Cobalt	Selenium
Antimony	Copper	Silver
Arsenic	Iron	Strontium
Barium	Lead	Tantalum
Beryllium	Magnesium	Tin
Bismuth	Manganese	Titanium
Boron	Mercury	Vanadium
Cadmium	Molybdenum	Zinc
Chromium	Nickel	Zirconium

OR COMPOUNDS OF:

Chlorates	Nitrate
Chloride	Phosphate
Cyanide	Sulfide
Ferricyanide	Sulfate
Ferrocyanide	Sulfite
Fluoride	Thiocyanate
Nitrate	Thiosulfate

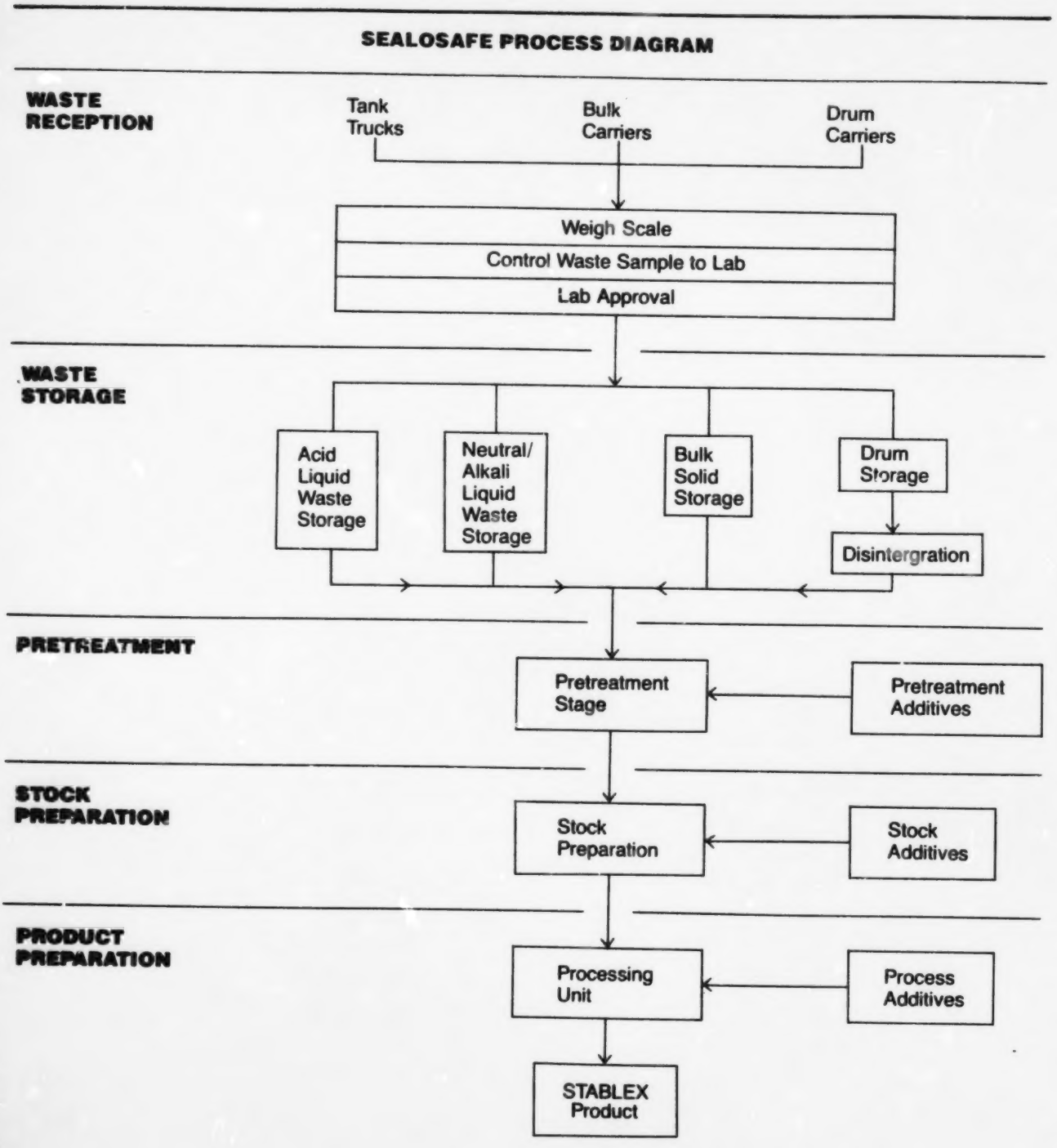

SEALOSAFE PROCESS DIAGRAM
WASTE RECEPTION
Tank Trucks
Bulk Carriers
Drum Carriers
Weigh Scale
Control Waste Sample to Lab
Lab Approval
WASTE STORAGE
Acid Liquid Waste Storage
Neutral/ Alkali Liquid Waste Storage
Bulk Solid Storage
Drum Storage
Disintergration
PRETREATMENT
Pretreatment Stage
Pretreatment Additives
STOCK PREPARATION
Stock Preparation
Stock Additives
PRODUCT PREPARATION
Processing Unit
Process Additives
STABLEX Product

FIGURE 1

DISCUSSION

P. Malone - I have two quick questions. You mentioned leachate is lined at that site. Is there a liner underneath the stablex material?

P. Grenier - We're on the fifth to twelfth meter of saturated clay, so its not a natural liner if you will.

P. Malone - Why did you take the cyanide to cyanate and stopped there? Was that just economy.

P. Grenier - Yes, in as much as the cyanide is not readily available from the material and remains solid.

THE SOLIROC PROCESS

Dr. J. M. Rousseaux
Tricil/Chemstabel Ltd.

Manuscript by Dr. J. M. Rousseaux

The Soliroc Process treats inorganic wastes containing heavy metals. In the process a chemical reaction takes place between the metals in solution and a proprietary reagent.

In the first step a monomer is synthetized which reacts with the metals in the second step to form an insoluble mass suitable for burial in a landfill.

Criteria for evaluating the inertness of the treated waste have been determined by simulating the environmental conditions imposed on the final product in a landfill site.

Essentially these conditions are: the nature and the quality of the ground-water, run-off water and rain-water.

During the operating phase of a landfill site the disposed waste must resist attack by acid rain etc., whereas the buried waste must resist the ground water action.

Cemstobel-Tricil proposes two different levels for stability assessment.

1. Immediate Stability: The control of effluent generated by the process must assure that no immediate contamination of the environment occurs.

2. Long-term Stability: This is evaluated by two tests:

   a) Static leaching test consisting of an acid titration of the waste, the result gives the intrinsic chemical resistance of processed waste.

   b) Dynamic leaching test consisting of flowing counter currently a stream of acid water through a column of treated waste. This test can predict the long-term stability of the product.

ENVIROSTONE GYPSUM CEMENT

Mark Joss
U. S. Gypsum Company

MANUSCRIPT BY MARK JOSS

The United States Gypsum Company has developed and patented a new product, ENVIROSTONE Gypsum Cement, a blend of gypsum cement and polymers designed specifically to solidify low-level radioactive wastes.

ENVIROSTONE Gypsum Cement solves many problems that face the nuclear industry by solidifying oils and organics, acidic wastes (without chemical adjustment) and ion exchange resins. It also allows greater amounts of waste per container than other binding media, thus using up less of the limited burial space, and reducing transportation costs. ENVIROSTONE Gypsum Cement meets or exceeds U.S. Nuclear Regulatory Commission requirements, providing a free standing monolithic solid with no free liquids throughout the cast. The United States Gypsum Company has issued a Topical Report outlining the development and testing done with this product. Copies of this report are available from the United States Gypsum Company, Department #173, 101 South Wacker Drive, Chicago, Illinois 60606.

The next step is to transfer this technology to the industrial waste area. Gypsum cements come in two basic forms - alpha and beta hemi-hydrate. Strengths can range from 15 to 15,000 psi. The set time can be quick, five minutes or extended out to 24 hours or more. This allows you to adapt this material to many types of mixing and handling conditions. Gypsum cements can be formulated to do many things and as with other binders, final waste form characteristics can be enhanced through the use of pre-treatment methods and proper site design and monitoring.

Gypsum cements can be sprayed wet, in the slurry form as a temporary or final landfill cover, and contain seed, and/or odor and rodent control additives. Gypsum cement sprayed dry, in the powder form, will act as a sponge drawing liquid waste into its matrix for easy removal during site clean up.

The United States Gypsum Company is the world's largest producer of gypsum cements and we serve Canada through the Canadian Gypsum Company. If you feel a gypsum cement might help solve one of the problems you face, let us know and we will be happy to help you fine tune a product to meet your specific needs.

DISCUSSION

G. Fell - Well I won't keep anybody too long, but thank you Mark. We must all be getting tired and I think there are a number of things I would like to bring up. I think it's been very interesting to see during the course of this day, how many key words have been used by either side, by the regulatory professional staff this morning and the vendors this afternoon. To give you an example, this morning we had such words as possibility, vagaries, prove, improper movement, worst case. For us in the vendors side, return on investment, foresight, inexpensive tests (again we're back to money prejudice), and then two very interesting things: historic obligation and economic balance. I really think what I would like to say is this. That out there in the field, as I am, dealing with local public officials, local public groups, what they look for from any of us, and Ron and David pointed out: if you're going to come up with an arbitrary standard, tell them that it is a standard that right now you believe is the best standard. Now we haven't heard that, and I think Mark was very good at bringing it up. So my point would be both to David and to Ron: Dave, we've got 30 years right now which you come back to your side. At least you've got a thirty year period. The point is, "Are we going to be around 100 years from now?", Ron's point. If we're going to have a standard, I think we should see tonight or today or coming off from this point, standards that we can go to the public and say here is a standard of this time and this knowledge. Two years from now, with research from the profs and the rest, will be that we will have a higher standard, but if we don't come away from this meeting with that type of work and knowledge, that type of understanding, I think the public, and when we go out, the public will then get a look at us and say: one more time, one more technology. That doesn't prove out. So thank you.

SECTION V

PROPOSED WTC/AEC PROTOCOL AND TERMS OF REFERENCE FOR THE COMPARISON STUDY

A PROPOSED PROTOCOL FOR ASSESSING THE ENVIRONMENTAL STABILITY OF SOLIDIFIED WASTES

Wastewater Technology Centre
and
Alberta Environmental Centre

November, 1983

INTRODUCTION

This document presents a battery of laboratory testing methods proposed to be used for assessing the environmental stability of solidified wastes. Existing methods from the fields of soil science, chemistry and radioactive waste management have been evaluated and adapted to testing solidified wastes. This background work was done at Environment Canada's Wastewater Technology Centre using synthetic wastes and a limited number of generic solidification processes. Input is sought on the usefulness of the protocol and on the applicability of the various test methods to wastes solidified using the wide range of commercially available technologies.

The proposed protocol does not include performance criteria. It is the role of regulatory bodies to select performance criteria based on correlation of the protocol's results with long term stability data and the expected disposal conditions.

APPROACH

Properties that make a waste hazardous include ignability, corrosivity, reactivity and leachability. The first three properties present hazards during handling, treatment and disposal operations. Leachability, on the other hand, represents a long term groundwater contamination threat for wastes disposed of on land. Several characteristics of a waste can contribute to creating a potential leaching problem. Large quantities of hazardous wastes are generated in aqueous matrices. The liquid fraction of an aqueous waste may contain high concentrations of soluble contaminants and can be considered an instantaneous leachate. A waste generated as a solid or the solid fraction of an aqueous waste offers little resistance to permeating water and constitutes a matrix where contaminants are highly mobile.

Stabilization/solidification is a treatment process that has the potential of reducing hazardous waste leachability. It may comprise (i) insolubilizing the contaminants present in the liquid, (ii) separating the resulting supernatant or absorbing it with dry additives, and (iii) creating a solid matrix by addition of a binder. The end product, a solidified waste, constitutes a matrix where the contaminants have reduced mobility.

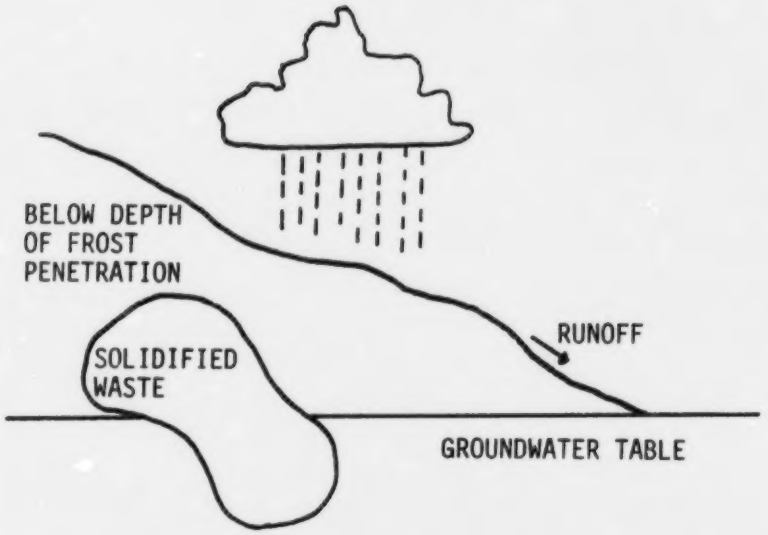
A laboratory assessment protocol for solidified waste should aim at evaluating how well a given solidification process has succeeded in rendering a specific waste non-leachable. The general characteristics to be tested include degree of mobility of contaminants in the matrix. Furthermore, those characteristics should be tested under conditions that represent a field leaching environment. For example, solidified wastes may be disposed of in a secure landfill or co-disposed with municipal garbage. It has also been proposed that solidified wastes be used for road base, filling old quarries, etc.

The objective of the assessment protocol is to provide a uniform basis for comparison of various solidified wastes. As such, it contains a battery of short term tests using defined environmental conditions. Various field disposal conditions are addressed by providing two series of test which simulate well-managed and mis-managed disposal scenarios (Figure 1). In the well-managed scenario, it is assumed that the waste is disposed of below the depth of frost penetration and therefore maintains its physical integrity. The landfill is well engineered and the waste is protected from direct contact with agressive leachants. The leaching environment is controlled by the solidified waste. In the mis-managed scenario, the solidified waste is subjected to weathering (freezing-thawing and wetting-drying cycles) and can therefore be broken down. It can be contacted with more agressive leachants such as acidic rain and municipal landfill leachate.

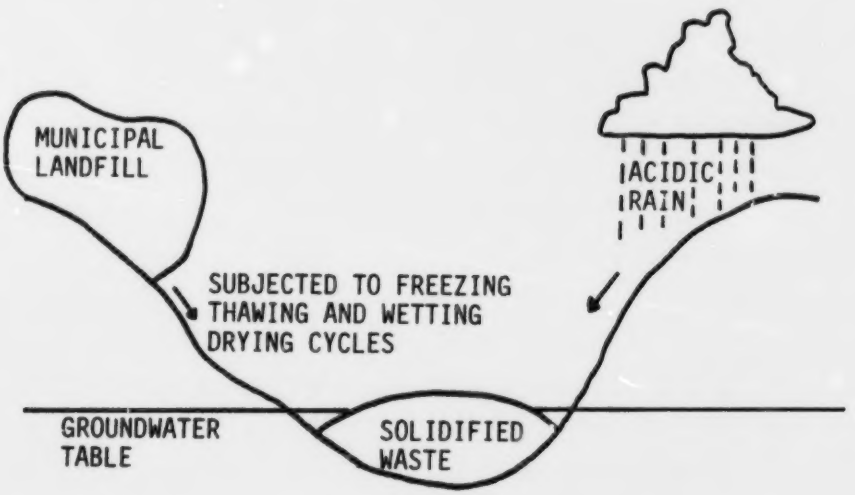
The results of the assessment protocol cannot be interpreted directly with respect to the long term stability of solidified wastes. As more information becomes available on long term stability through use of accelerated testing methods and mathematical modeling, it will be possible to better assess the value of the protocol.

ASSESSMENT PROTOCOL

The elements which comprise the assessment protocol are presented in Table 1. They have been grouped into three categories which provide information on: i) the process, ii) the physical properties of the solidified waste and iii) the environmental stability of the solidified waste.



i) well-managed scenario



ii) mis-managed scenario

FIGURE 1. DISPOSAL SCENARIOS CONSIDERED IN THE ASSESSMENT PROTOCOL

The process information has to be provided by the producer of the solidified waste. It includes characteristics of the raw waste, weight change resulting from solidification and information on curing time and environment.

The physical properties to be measured on the cured solidified wastes include water content, bulk density and solids specific gravity. These properties allow calculation of characteristics such as porosity and degree of saturation and can also be correlated to the environmental stability data.

The environmental stability category includes physical and leaching tests to evaluate well-managed and mis-managed disposal scenarios, as described in the previous section. In the well-managed disposal scenario, an equilibrium leaching test is used to measure the solubility of contaminants while a dynamic leaching tests is used to evaluate their mobility. Mobility, expressed as a leachability index (LX) (American Nuclear Society, 1981) includes the effects of a contaminant diffusivity, matrix tortuosity and chemical reaction (Cote, 1983). No dynamic leaching test has been included in the mis-managed disposal scenario since most solidified wastes break down rapidly when submitted to weathering (Bartos and Palermo, 1977; Bruce et al 1981). Under the resulting high surface area to leachant volume ratios, it is assumed that equilibrium conditions will prevail.

Tables 2 to 12 present each test included in the assessment protocol, its significance and current status of development.

TABLE 1. ASSESSMENT PROTOCOL

Process Information

Characteristics of the raw waste
Weight change factor
Curing time and environment (temperature and humidity)

Physical Properties

Water content (Table 2)
Bulk density (Table 3)
Solids specific gravity (Table 4)

Environmental Stability

Well-managed scenario:
Unconfined compression strength (Table 5)
Permeability (Table 6)
Equilibrium leaching test (Table 7)
Dynamic leaching test (Table 8)

Mis-managed scenario:
Weathering (Table 9)
Acid titration (Table 10)
Low pH leaching test (Table 11)
Sequential chemical extraction procedure (Table 12)

TABLE 2. WATER CONTENT

Description

Dry a replicated sample at 60°C to constant weight.

Significance

Used in calculation of contaminant and matrix porosity. Correlated to weathering resistance and leaching mobility (Cote and Hamilton, 1983).

Status of Development

Use ASTM standard method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures (D2216-80)

TABLE 3. BULK DENSITY

Description

Weigh a sample of known volume

Significance

Expresses the degree of compaction of a solidified waste slurry. Used in porosity and contaminants concentration calculations

Status of Development

Not required.

TABLE 4. SOLIDS SPECIFIC GRAVITY

Description

Use a pycnometer to measure the ratio of the weight in air of a given volume of sample to the weight in air of an equal volume of distilled water.

Significance

Used in calculation of matrix porosity.

Status of Development

ASTM Method D854-58 for Specific Gravity of Soils has been used. Comparison of this data with that derived from mercury intrusion data did not agree (mercury intrusion is primarily intended for measuring the pore size distribution).

TABLE 5. UNCONFINED COMPRESSION STRENGTH

Description

A laterally unconfined sample is axially loaded until failure using a compression machine.

Significance

The unconfined compression strength is indicative of the solidified waste ability to keep its physical integrity when subjected to the stresses imposed under disposal conditions (overburden pressure, freeze & thawing cycle, etc.). It can also be used to monitor the degree of curing.

Status of Development

Use ASTM Test for Compressive Strength of Hydraulic Cement Mortars (L109-80).

TABLE 6. PERMEABILITY

Description

Solidified wastes typically have permeabilities of the order of magnitude of clays (Bartos and Palermo, 1977). Permeability measurement of fine-grained soils was reviewed by Olson and Daniel (1979) and Roberts and Nichols (1981). For Darcy's law to be applicable (i.e., the permeability coefficient is independent of the sample's water content and of the pressure head), a saturated sample must be used in the test. This condition will lead to the measurement of maximum permeability, i.e., the worst case condition. The test is conducted on a cylindrical sample wrapped into a rubber membrane. The sample is placed into a triaxial cell where lateral pressure can be applied to minimize the flow of water between the sample wall and the membrane. Use of a triaxial cell also facilitates saturation of the sample using de-aerated water and application of back pressure.

Significance

The permeability of a solidified waste will determine the relative importance of the two main leaching mecnanisms, (i) convective transport via flow of water through the matrix and (ii) diffusive transport of contaminant within the pore fluid of the matrix.

Status of Development

There is no available standard method to measure the permeability using a triaxial cell. A triaxial cell has been set up and successfully used to saturate samples. Measurement of permeability requires more work.

TABLE 7. EQUILIBRIUM LEACHING TEST

Description

This test is conducted by mixing a sample of finely ground solidified waste with distilled water using the minimum liquid to solid ratio. The test should be run for a period of time sufficient for equilibrium to be attained. The liquid should then be separated from the solids and analyzed for the contaminants of interest.

Significance

The measured concentrations are indicative of the degree of insolubilization obtained through pretreatment and solidification of the waste.

Status of Development

Experiments to determine the test duration need be done.

TABLE 8. DYNAMIC LEACHING TEST

Description

The test is used to generate a leachability index (LX) which is an expression of the contaminant mobility under the prevailing leaching environment.

In the dynamic leaching test, a solidified waste specimen of known surface area is immersed in distilled water at a specified leachant volume to specimen surface area ratio. The leachant is replaced at frequent intervals, and the masses of the species of interest leached during each interval are determined. The test is non-agitated because it is assumed that the migration rate of the contaminants in the leachate is several orders of magnitude larger than in the solid matrix, thus eliminating concentration gradients in the leaching medium.

Significance

For the cases where the leaching rate controlling mechanisms is diffusion through the solid matrix, LX $-\log D_e$, the negative log of the effective diffusion coefficient. Interpretation of the leachability index as a diffusion coefficient and extrapolation of the dynamic leaching test results using the diffusion coefficient in a mathematical model are further discussed in the American Nuclear Society (1981) proposed protocol and by Cote and Hamilton (1983).

Status of Development

Testing protocols as proposed by the American Nuclear Society (1981) and the US EPA (Environmental Laboratory, 1980) are not directly applicable to solidified hazardous wastes because of the large range of leachability encountered and because of limitations in the analytical detection of the chemical species in the leachate. Use of a variable leachant renewal frequency was shown to solve this problem (Cote and Isabel, 1983). The test was used to compare the

leachability of several generic solidification processes (Cote and Hamilton, 1983). A modification to the test protocol, involving the use of a modified soxhlet extractor is now being evaluated in order to improve the precision of the measured concentration and better meet the assumptions of the simple diffusion model used to interpret the test results.

TABLE 9. WEATHERING

Description

This test attempts to accelerate the effects of freezing/thawing and/or wetting/drying cycles on solidified wastes. The specimen's weight loss is monitored as function of the number of cycles. The test is terminated when either a predetermined number of cycles or a maximum weight fraction lost is attained.

Significance

The resistance to weathering will determine the solidified waste surface of contact with the leachant.

Status of Development

Two ASTM standard methods, D559-57 Wetting and Drying Test of Compacted Soil-Cement Mixture and D560-57 Freezing and Thawing Tests of Compacted Soil-Cement Mixtures, have been used for evaluation of solidified wastes (Bartos and Palermo, 1977; Bruce et al, 1981). It has been suggested that the use of a wire brush between each cycle to measure the weight loss might be too severe for solidified wastes. At the end of the test, the comminuted fraction should be characterized using ASTM method D422-63 for particle-size analysis of soils. This method needs more development work.

TABLE 10. ACID TITRATION

Description

A titration is performed using a strong acid (1N HNO_3) on a specimen with a geometrical surface area to unit weight ratio as obtained from the weathering test. Use of a low rate of acid addition, i.e., approx. 1.0 meq/g.hr allows for pseudo-equilibrium to be maintained during the test for specimens crushed to pass a 100 mesh sieve (WTC unpublished data). The results are presented as a titration curve down to pH = 5.0.

Significance

This test aims at measuring the pH buffering capacity of solidified wastes. For specimens broken down during weathering, the test will measure close to equilibrium conditions. For samples not affected by weathering, the acid neutralization capacity will be kinetically limited.

Status of Development

Preliminary tests have been run manually at the WTC. An automated, computer controlled set-up is being developed and needs to be tested.

TABLE 11. LOW pH LEACHING TEST

Description

It is proposed that a modified EPA Extraction Procedure be used to evaluate the leachability under acidic-leaching conditions. The modification would consist of using a waste geometrical surface area to unit weight ratio as obtained from the weathering test.

Significance

In the Extraction Procedure, the maximum amount of acid added is 2 meq per gram of waste. This corresponds to the maximum amount of acid generated from the biodegradation of municipal refuse when municipal refuse and an industrial waste are co-disposed in a ratio of 19 to 1 (EPA Newsletter, Solid Waste News Brief, May 1979).

The quantity of acid per unit weight of solidified waste resulting from exposure to acid rain can also be estimated:

solidified waste
- volume = 1 m^3
- surface area = 6 m^2
- bulk density = 1 500 kg/m^3 = 1.5 x 10^6 g/m^3

acid rain
- rain fall: 0.5 m/year
- concentration factor = 100 (i.e., 1 m^2 of exposed solidified waste drains 100 m^2 of rain)
- pH = 4
- duration = 100 years

$$\text{volume of rain} = 0.5 \frac{m}{year} * 600\ m^2 * 100\ \text{years}$$

$$= 30\ 000\ m$$

$$\text{acidity} = 10^{-4} \frac{eq}{L} * 10^3 \frac{meq}{eq} * 30\ 000\ m^3 * 10^3 \frac{L}{m}$$

$$= 3.0 \times 10\ meq$$

$$\frac{\text{acidity}}{\text{unit weight}} = \frac{3.0 \times 10^6 \text{ meq}}{1.5 \times 10^6 \text{ g}} = 2.0 \frac{\text{meq}}{\text{g}}$$

This is equivalent to the acidity available from codisposal.

Status of Development

Use the US EPA Extraction Procedure with the proposed modification.

TABLE 12. SEQUENTIAL CHEMICAL EXTRACTION PROCEDURE

Description

The sequential chemical extraction procedure is used to categorize elements into five fractions:

Fraction A: exchangeable metal ions
Fraction B: surface oxides and carbonate-bound metal ions
Fraction C: metal ions bound to Fe-Mn oxides
Fraction D: metal ions bound to organic matter and sulfides
Fraction E: residual metal ions

Each fraction is obtained by extracting a sample using chemical solutions of increasing agressiveness.

Significance

This test, limited to metals, provides valuable information on their morphological binding characteristics and as such, on availability and mobility.

Status of Development

The method was developed by Tessier et al (1979). It has been used on several samples at the WTC.

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A COMPARATIVE EVALUATION OF WASTE SOLIDIFICATION TECHNOLOGIES

TERMS OF REFERENCE

Conducted by:
Wastewater Technology Centre
Alberta Environmental Centre

With the participation of:
Environment Canada
U.S. Environmental Protection Agency

November, 1983

CONTENTS

	Page
1. INTRODUCTION	216
2. OBJECTIVES	216
3. APPROACH	216
4. PROCEDURE	218
5. SCHEDULE	223

1.0 INTRODUCTION

Regulatory agencies are involved in the evaluation of waste stabilization/solidification technology because they are faced with the task of selecting or approving hazardous waste treatment facilities and have the responsibility of maintaining groundwater quality.

Assessment of most environmental engineering technologies can generally be achieved using data published by independent researchers. However, an unusual situation prevails with waste stabilization/solidification technology, where a majority of the processes are proprietary, the additives are "secret" and most of the performance data are only available from the vendors. Furthermore, assessments conducted to date have been done using a wide variety of testing methods which makes a comparative evaluation of different processes very difficult.

2.0 OBJECTIVES

The objectives of this comparison study of waste stabilization/solidification technologies are to:

i) determine the applicability of various commercially available stabilization/solidification technologies to a wide range of hazardous wastes

ii) compare the environmental stability of the solidified wastes on a common basis using the WTC/AEC assessment protocol.

3.0 APPROACH

The raw wastes used in the comparison study will be selected by the Wastewater Technology Centre and Alberta Environmental Centre (WTC/AEC) in order to cover the range of wastes that can be processed by commercially available stabilization/solidification technologies. The typical list presented in Table 1 is subject to modification/addition/deletion after discussion with the parties involved.

The comparison study will be conducted following a strict procedure as described in Section 4. It will involve four parties:

Party	Task
- WTC/AEC	- select raw wastes - perform testing on solidified wastes - write final report
- vendors	- perform stabilization/solidification
- 3rd party	- acts as an intermediate between WTC/AEC and the vendors
- EC/EPA	- attend solidification operation

Involvement of a 3rd Party and of Environment Canada and the Environmental Protection Agency (EC/EPA) regional offices makes the signing of secrecy agreements unnecessary. The 3rd Party and EC/EPA officers will ensure that the results are unbiased and provide a high degree of protection to the regulatory agencies (testing results are reliable) and to the vendors (proprietary information is not disclosed).

The first objective of the study, to determine the applicability of various technologies to different wastes will be achieved by each vendor prior to completion of the final report. As illustrated in Figure 1, each vendor will be offered the total number of wastes. During the course of the study, each vendor will have three opportunities to reject the wastes for which its technology is not applicable:

Step 5; based on the characteristics of the wastes,
Step 8; based on preliminary experimentation on the wastes, and
Step 20; based on the results of the assessment protocol performed by WTC/AEC.

This exercise will be conducted by each vendor without the involvement of WTC/AEC and without knowledge of competitors' results.

The second objective of the study, a comparative evaluation of the various technologies, will be based on the WTC/AEC proposed assessment protocol. The comparative evaluation will be done only on those wastes that each vendor considers its technology to be applicable to. It will also be done on the optimal formulation of each process.

Since two laboratories are involved, the study will include a minimum amount of quality control/quality assurance through evaluation of inter and intra laboratory reproducibility.

4.0 PROCEDURE

The relationships between the four parties during the conductance of the comparison study are illustrated in Figure 2. The various steps involved are described below.

Step 1. Selection of raw wastes

WTC/AEC select a number of raw wastes to be included in the comparison study. The wastes selected should cover the range of wastes that may be treated by commercially available stabilization/solidification processes. Each waste will be characterized for the following parameters:

- pH
- bulk density
- total solids
- suspended solids
- redox?
- concentration of contaminants of interest

A preliminary list of raw wastes is given in Table 1.

Step 2. Ship raw wastes

WTC/AEC will ship the raw wastes, together with the characterization data to the 3rd party.

Step 3. Divide raw wastes into two lots

Upon receipt of the raw wastes from WTC/AEC, the 3rd party will randomly assign a raw waste number to each waste and divide each raw waste into two lots, lot A and B.

Step 4. Send raw waste description

The 3rd party will send to each of the the participating vendors the characteristics of all the raw wastes included in the comparison study. Each waste will be identified by its number and generic name.

Step 5. Raw wastes for experimentation

Upon examination of the raw waste list received from the 3rd party, each vendor will decide which wastes they want to experiment with and inform the 3rd party.

Step 6. Send raw wastes (Lot A)

The 3rd party sends to each vendor those raw wastes (Lot A) that were requested (from Step 5).

Step 7. Experimentation (Lot A)

Each vendor is given a period of time to experiment on raw waste Lot A. This step allows each vendor to decide, based on practical experience, which raw waste they want to receive for the comparison study and also allows them to optimize the process for each raw waste. The vendors do not have to communicate the results of these experiments to the 3rd party or the WTC/AEC.

Step 8. Raw wastes for comparison study

After experimenting on raw waste Lot A, each vendor indicates to the 3rd party which raw wastes they want to receive for solidification in the comparison study.

Step 9. Send raw wastes (Lot B)

The 3rd party sends raw waste Lot B to the EC/EPA regional office closest to the vendors facilities. Each raw waste sample is sealed and identified by its' raw waste number only. For each raw waste sample, the 3rd party will also send a solidification processing sheet, solidified waste specimen molds and ID tags.

The solidification processing sheet, to be completed during the solidification operation contains the process information as described in Step 11.

The number of solidified waste specimen molds will depend on the assessment protocol and has yet to be specified. A number of replicates will be provided as discussed in Step 11.

One solidified waste specimen ID tag will be provided for each specimen. It will bear a unique number. The correspondence between that number, the raw waste sample and the vendor will be known only by the 3rd party.

Step 10. Appointment

The EC/EPA regional office representative makes an appointment with the vendor(s) within his jurisdiction to deliver the raw waste sample Lot B and witness the solidification operation.

Step 11. Solidification (Lot B)

The solidification operation will take place at the vendors facilities in the presence of the EC/EPA regional office representative. This can be done in a minimum of time (1 day) since the vendor knows the optimal formulation to be used for each raw waste sample (from Step 7) and can have all the additives ready for the solidification operation. Triplicates of each specimen are prepared to provide sampling for quality control/quality assurance.

During the solidification operation, the EC/EPA representative will fill out the solidification processing sheet (Figure 3). The sheet will be returned to the 3rd party and keep on file until Step 21.

After the solidified waste slurry has been poured into the molds, the EC/EPA representative will tag each sample by inserting the tag string into the slurry. The tag identifies the sample and the day it was solidified. This procedure will ensure that each sample will keep its unique ID number throughout curing, transportation and testing.

The solidified waste specimens (unmolded after 48 hours) are cured 28 days at the vendor's site under controlled environmental conditions (20°C and 100% humidity).

Step 12. Send solidification processing sheets

The EC/EPA representative returns the solidification processing sheets to the 3rd party. They are kept by the 3rd party until Step 21.

Step 13. Send solidified waste specimens

After 28 days of curing, the solidified waste specimens are shipped by the vendors to the 3rd party.

Step 14. Collect solidified waste specimens

The 3rd party receives the solidified waste specimens from the vendors. The triplicates are handled in the following manner:

- one specimen for each test in the assessment protocol is sent to WTC
- one specimen for each test in the assessment protocol is sent to AEC
- the third series of specimens is sent either to WTC or AEC in order to obtain inter and intra laboratory reproducibility data.

Step 15. Send solidified waste specimens

The specimens from all the vendors are sent to WTC/AEC for testing.

Step 16. Perform testing

WTC/AEC perform the tests comprising the assessment protocol, exactly 56 days after solidification took place. Test result sheets are completed for each specimen tested.

Step 17. Send test results

The test results from each specimen are transmitted to the 3rd party.

Step 18. Assemble test results

The test results received from WTC/AEC are assembled by the 3rd party according to raw waste number and vendor.

Step 19. Send test results

The 3rd party sends each vendor the test results for each raw waste solidified. The vendors must not dissiminate the test results prior to publication of the final report.

Step 20. Raw wastes for final report

After examination of the test results, the vendors indicate to the 3rd party which raw wastes they want to be included in the final report.

Step 21. Raw wastes for final report

The 3rd party sends to WTC/AEC the solidification processing sheet (Figure 3) of each waste sample (of each vendor) to be included in the final report. This sheet allows WTC/AEC to associate the solidified waste specimens tested with the raw wastes and the vendors.

Step 22. Specimen residuals

The specimen residuals are returned to the vendors.

Step 23. Final report

WTC/AEC prepare and publish a final report which will include the following information:

- a list of all the wastes that were offered to all vendors,
- a list of vendors and the wastes they solidified
- the assessment protocol results,
- a comparative analysis of the results

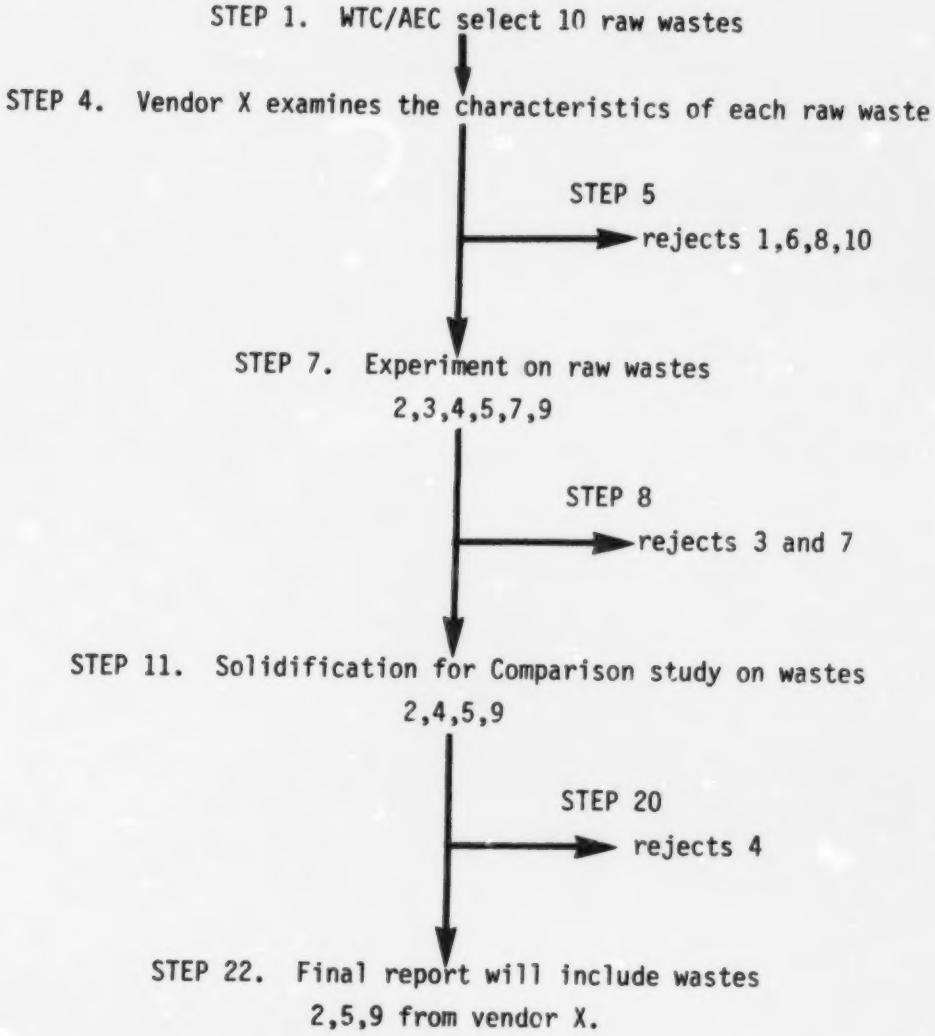
5.0 SCHEDULE

The comparison study including the main "time consuming" steps is presented in Figure 4.

TABLE 1. LIST OF WASTES TO BE INCLUDED IN THE COMPARISON STUDY

Waste	Typical Contaminants
WTC synthetic solution	As, Cd, Cr, Pb, Phenol
WTC synthetic liquid sludge	As, Cd, Cr, Pb
PCB contaminated soil	PCB's
Organic tank bottom sludge	Several chlorinated organics
PCB contaminated oil	PCB's
Latex wastes (pulping ops)	Organics
Spent sulfite liquor (pulping ops)	Sulfite oxalates organics
Mercury Cell	Hg
Plating Waste	CN, metals

Note: To be finalized after discussion with the parties involved.


STEP 1. WTC/AEC select 10 raw wastes
STEP 4. Vendor X examines the characteristics of each raw waste
STEP 5
rejects 1,6,8,10
STEP 7. Experiment on raw wastes
2,3,4,5,7,9
STEP 8
rejects 3 and 7
STEP 11. Solidification for Comparison study on wastes
2,4,5,9
STEP 20
rejects 4
STEP 22. Final report will include wastes
2,5,9 from vendor X.

N.B. refer to Section 4 for description of the steps.

FIGURE 1. EXAMPLE OF HOW A VENDOR WILL DETERMINE THE RAW WASTES THAT WILL BE INCLUDED IN THE FINAL REPORT OF THE COMPARISON STUDY

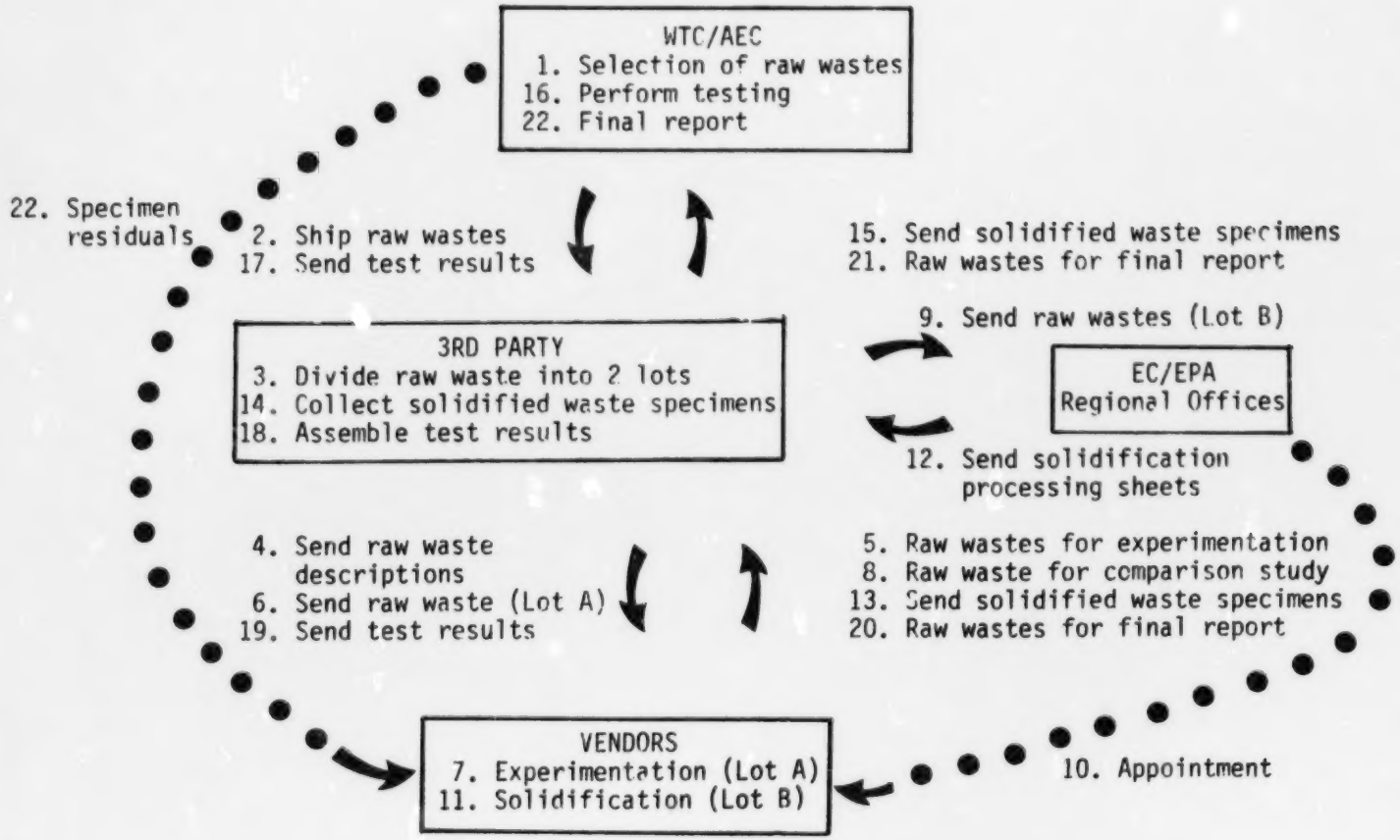

WTC/AEC
1. Selection of raw wastes
16. Perform testing
22. Final report
22. Specimen residuals
2. Ship raw wastes
17. Send test results
15. Send solidified waste specimens
21. Raw wastes for final report
9. Send raw wastes (Lot B)
3RD PARTY
3. Divide raw waste into 2 lots
14. Collect solidified waste specimens
18. Assemble test results
EC/EPA
Regional Offices
12. Send solidification processing sheets
4. Send raw waste descriptions
6. Send raw waste (Lot A)
19. Send test results
5. Raw wastes for experimentation
8. Raw waste for comparison study
13. Send solidified waste specimens
20. Raw wastes for final report
VENDORS
7. Experimentation (Lot A)
11. Solidification (Lot B)
10. Appointment

FIGURE 2. STEPS IN THE COMPARISON STUDY

SOLIDIFICATION PROCESSING SHEET

Company: _____

Generic description of the process: _____

Raw Waste Sample No. _____

1. Initial weight of raw waste sample _____g

2. Cumulative weight of additives _____g

3. Cumulative weight of sidestreams _____g

4. Solidified waste batch weight (1+2-3) _____g

5. Sidestream sample ID's _____
   _____

6. List of solidified waste samples which have been tagged

Size	Tag ID
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

7. Company Representative signature: _____ Date: _____

   EC/EPA Representative signature: _____ Date: _____

FIGURE 3. SAMPLE OF THE SOLIDIFICATION PROCESSING SHEET

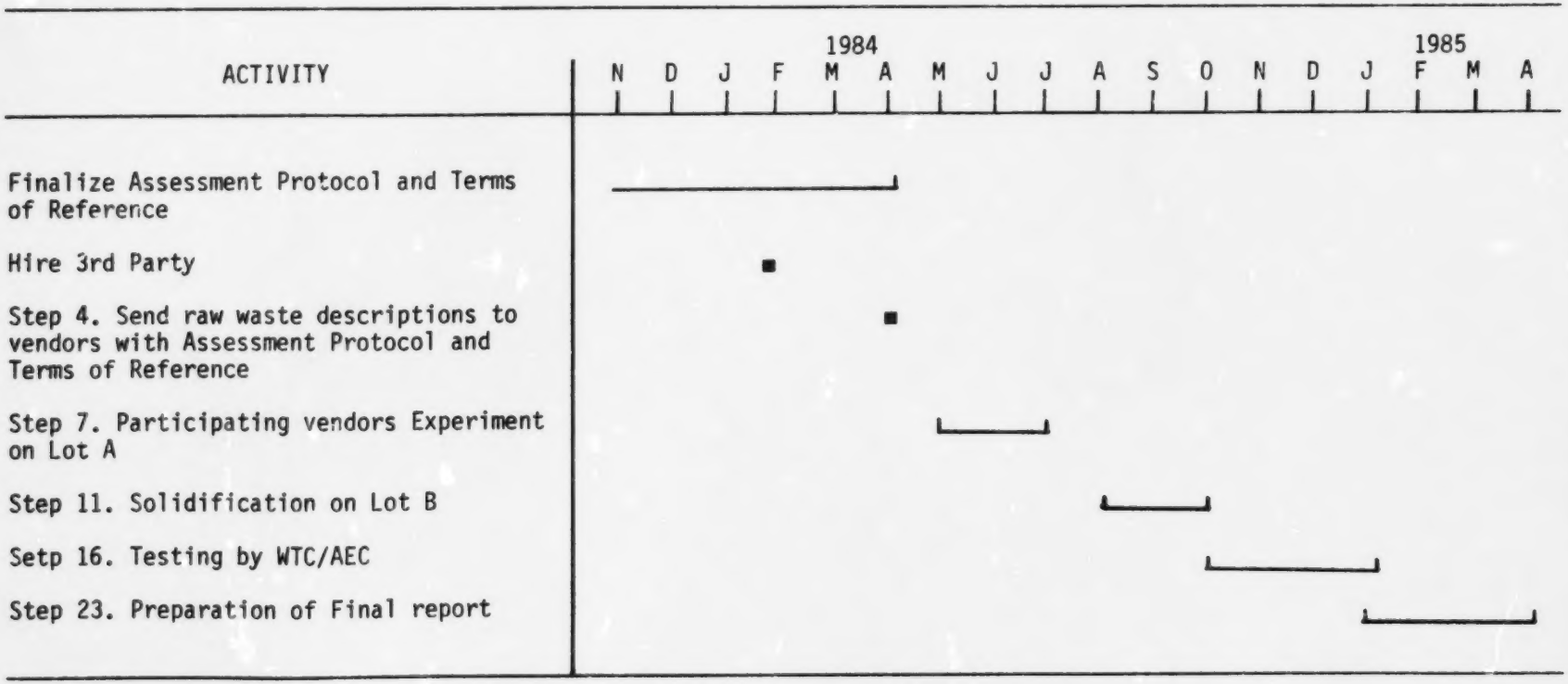

ACTIVITY
1984
1985
N D J F M A M J J A S O N D J F M A
Finalize Assessment Protocol and Terms of Reference
Hire 3rd Party
Step 4. Send raw waste descriptions to vendors with Assessment Protocol and Terms of Reference
Step 7. Participating vendors Experiment on Lot A
Step 11. Solidification on Lot B
Setp 16. Testing by WTC/AEC
Step 23. Preparation of Final report

FIGURE 4. PROPOSED SCHEDULE INCLUDING THE MOST TIME CONSUMING STEPS

SECTION VI

LIST OF CONCERNS

LIST OF CONCERNS

Notes: This was a "brain-storming" session. The following list is a reproduction of what was written during the session. The bracketed comments are given to elaborate or clarify the list. These have been condensed based on the comments given during the session.

1. Vendors participation. (Would they participate?)

2. Process specifics. (Process details, especially use of additives should be considered).

3. Blending opportunity vs. individual. (Would blending of sample raw wastes be permitted?)

4. Sample homogeneity. (In splitting and distributing raw wastes, homogeneity must be preserved).

5. Time effect of organics. (Deterioration of organic components must be considered).

6. Time effect of treated wastes. (Changes in composition/properties with time must be considered).

7. Waste/Additive ratio. ("Dilution effect" should be considered).

8. Selection of wastes.

9. Time to treat wastes. (The suggested time of 1 day might not be sufficient, example: cyanide).

10. Demolding time. (The suggested time of two days might not be appropriate for some processes).

11. Whole concept:

    - Test details. (We don't know what they are, whether or not proven).
    - The management scenario (not acceptable).
    - Criteria of acceptability (not yet defined; should be based on environmental impact).
    - Implications of withdrawal (guilty by default).

12. Definition/Selection of third party-security.

13. Objectives? (not clear)
    - process potentials (acceptability criteria not defined)
    - method development

14. Too many options for opting out by vendors.

15. Total system vs. material. (The total system, including disposal site specifics, should be considered, not just the solidified wastes).

16. Bench-mark process - as basis. (Well known, generic processes should be included in the comparison).

17. Field vs. Lab results. (Results in the field are better than those in the lab.).

18. Other processes to be included? (process other than solidification should be included; example absorption with "kitty litter").

19. Not necessarily "best" process is used. (In practice, vendors match the solidification process with disposal site; example non-landfill or secure landfill).

20. Realistic processes not used in study. (This should not be an exercise in technology. Solidification is only part of total waste management).

21. Complete characterization of wastes. (Not only "contaminants" of interest should be measured).

22. Direction? (Analogy presented: Columbus, not knowing where he was going, where he was, where he had been, but we got here).

23. Alternatives. (Processes other than solidification, including non-treated wastes, should be included).

24. Assessment of raw wastes. (control).

25. Bench-mark process - before comparative. (These should be subjected to test protocols).

26. Definition of severity of test and reason. (Everyone should know what is to be part of the comparison study).

SECTION VII

OPEN DISCUSSION

SECTION VII

OPEN DISCUSSION

N. Mossholder - I think in principle we are interested in this kind of a study. However, we are only interested and would only consider participating if it is done correctly. We are not interested in participating in a study that is filled with compromises for the purpose of getting it done to meet a regulatory time frame. I don't feel that that is in the best interest of the industry.

H. Buzbee - I think we see a lot of problems here this morning. Chemfix is willing to participate in this type of work if it is necessary. I don't want to be involved in another comparative study per se. What I would like to be involved with and I would commit a lot of our company's time in the production of the proper evaluatory tests that I can use to determine the possible success of using Chemfix on a particular waste. The tests that I will want to see are ones that assess the applicability of a process in a given disposal scenario. For example, we have heard from Mr. Mullen, he has a process that works very well when he disposes of his waste in his manner. Chemfix does not own or operate a disposal site, so our process is completely different. The generator has more control over the end product. There are different ways that we need to test a product. Maybe as we were talking over here a minute ago there might be a bank of 10 or 15 tests that a performed on a product. If you going to dispose or store the waste in a particular manner you use tests 7, 8 and 9 and throw out the other tests. What I want to do and what I will work very hard toward is producing the proper tests methods. If we get general agreement that there is going to be a comparative study and other people are going to be in it I am not going to be left out because I'm very comfortable with what I can do with wastes. I don't want to make this my prime objective over the next few years - a comparative study.

H. Mullen - I like to supplement that and say "Yes, I support both of the last statements". We would not be interested if all you are going to do is run these leaching tests and publish comparative tables. If you are going to tell us what you feel is acceptable to protect the environment, how the environment should be protected, let us determine whether our process can do that or not. That is a different matter. Nobody has come forward with anything like that yet

either in the States or up here. I would submit to you that you might be better advised to ask each vendor to come back to you with a protocol for analyzing and assessing his process. This is how we do it. This is the test that we feel is applicable to our process and why and these are the results that we look at. Then you can set up your whole test program on that basis.

P. Hannak - I feel that is very valuable. Actually our suggestions are that these be included in the testing protocol. They are just initiating thoughts and we like to have the input of the vendors for any further testing to complete the testing protocol.

J. Connor - We are quite willing to participate in the comparison study. I would just like to point out something. It seems to me that the study is not only going to compare or evaluate the various processes but it is also going to evaluate the tests that we are using, and if it is understood in that respect, that these are most of the tests that have been proposed in the paper that I got here last night. As somebody pointed out these are not standard specification tests of any sort now. And it is understood that in fact the program will evaluate those tests as usable tests and I think it is a reasonable thing to do.

E. Shuster - Although I can not commit Solidtek, I certainly feel that Solidtek will very much want to participate in a meaningful program that comes out of this and I think some of the factors that the real world folks, as we like to be called, feel are important to this, are included. I think really what we are looking at is a broadening so that we are not looking at this little segment of the treatment industry and these treatment processes that have some similarities and differences but looking at it on the overall scale of 1 - 10 in the waste processing protocols, starting with no treatment as an option and then going through some of these others and we will probably have these in a little group that will be somewhere between 8 and 9. But I think really most of us here feel that we all have processes that will meet the environmental goals if the goals and protocols are set down in writing, in something other than jello, that we are going to be able to shoot at a fixed target for a while.

H. Mullen - I have one more comment, suggestion. I would strongly suggest that you eliminate this mis-management concept that you have included. That is very dangerous information. No matter what you do with this test. It is going

to be published and people are going to read it. The public is going to get a hold of it and even though it is a mis-management concept and clearly labelled. The public is not going to perceive it that way and therefore we are going to have much more difficulty in siting facilities.

P. Hannak - Just one comment. If you have just well managed disposal sites we would not be here.

N. Mossholder - I would like to second Hugh's last comment. There is a difference between mis-management scenarios and un-managed scenarios and destructive testing, and I have used some of the test methods that were proposed to be destructive testing and that's what I am very much against. Because there you set up a situation where all processes must fail and it's very easy for the public to mis-interpret those results as being none of the processes work, and I think that is what Hugh's afraid of and certainly what I'm afraid of. I would not be interested in any kind of destructive testing in this kind of a study.

J. Rousseaux - I agree with Nelson when he says that destructive tests are inadequate to evaluate the stability of the treated waste. For example, going to the protocol I saw the titration at pH 5 with one normal nitric acid. This is extremely destructive and if you put a block of stainless steel in this condition, you would find out that iron as well as chrome would come out. Then I think we would have to reconsider this type of test.

P. Cote - Just a comment on your comment. The acid titration has no chemical analysis associated with it. In other terms, we are not trying to generate a leachate. We just want to measure the intrinsic buffering capacity of the waste. Want to know how many milli equivalent of acid are needed to reach a pH of 9-8-6-5.

H. Busbee - Reading the tests that are proposed, maybe I didn't read them well enough, but I didn't see where it was really any different in a lot of respects from what I look at in some of my testing now. I don't think it is overly, I don't know if I would call it destructive testing or not. I would want to talk about and spend most of the time discussing what tests can be added here. These are a first blush by the Canadian Group. There are some things

that I would not want to do in these things and some modifications I would make, some completely different tests. I don't know what I would like to run the Chemfix product, how I would like to test it. But that is what I hoped would come out of this is, how can I change my testing methods to assess whether or not Chemfix is the best alternative in a specific disposal option.

A. Liem - Perhaps we should summarize this and see if we want to discuss this or not. Am I correct in saying that there is an agreement in principle by the Vendors to participate in this kind of study with details to be decided later on. Is that a fair statement? I think it was also raised what actually the test methods themselves should be. A suggestion was made to include Vendor's own test protocol and in fact the criteria of acceptability has come up quite often. How do you know if that is good or not good based on the test? I was just wondering how to proceed with this. One is we could discuss all those concerns there or we can just forget them. The point is, is it a good time to discuss this for the purpose of arriving in a certain direction.

N. Mossholder - We have just about an hour until some of us are going to have to depart and I think in that length of time we are not going to get substantive discussion accomplished. I think we should try to organize in the time we have available. Perhaps appoint some test groups or committees to work on various aspects of this and arrange to meet again at some future time to review the discussion of those committees.

T. Bridle - I think we have to do that. It would have been lovely if Pierre could have spent some time going through the protocol because I think it would have allayed a lot of huge fears, would have reinforced some of the things that you said, Hudson. Very difficult to write down your inner thoughts on what you are trying to achieve from a certain test and Pierre has tried to do that and I think if we had the time for him to show the data, more importantly, show the reams of leaching data that we have accumulated at Burlington up to 9 months almost 12 months of leaching data, which hopefully is going to be long enough. What would you consider as a valid test, how long is long enough? We don't have time to do that and I agree that the only thing we can do is try to strike up maybe just one committee, maybe two committees. Whether you need one to look at protocols and one to look at the terms of reference, because I am sure the

vendors obviously have a direct interest in both those facets and whether they can be represented on both committees. May make it too difficult to have two. Maybe you need one steering committee with one member from each vendor and one member from each potential other actor within all the parties that would be involved. You do have a small group of people.

N. Mossholder - From the vendor's side, I think there are three basic issues. The test protocols. The terms of reference and the acceptance criteria. I don't know whether those can be logically split among three committees or not. It is hard to split the test protocols and the acceptance criteria.

P. Cote - There is a number of vendors present here but there are also a number of vendors who didn't come here and that would certainly participate in the comparison study if we invite them. I just raise the question, if we form a task force or a working group with some representation of the vendors, I wonder if at some point these other people will not feel left out.

N. Mossholder - My own feeling is that whatever task force we form should be open to participation by anyone who feels interested enough to want to be involved. We shouldn't limit any of them.

A. Liem - Perhaps we can look at what kind of task force we want to form and then composition and perhaps deadline as a way of moving this quickly: actually, assessing the test protocols themselves and talking about the terms of reference, talking about the criteria of acceptance. Let's look at the objective of the tasks groups and look at the composition and when we want to do it. Is that fair enough?

J. Salloum - I am just thinking in terms of logistics and planning committees and meetings and things. If you are going to get anything done you are going to have to have something less than a 50 people committee or you are going to spend all your time discussing things, it seems to me. How many commercial vendors, there were 6 here, but how many Pierre mentioned that there were others who were not here. How many more might there be - another 6 to 10.

P. Hannak - There are at least 29 listed vendors for solidification processes. Some of them do not exist any more so I would estimate that number who would come about 15.

J. Salloum - All I was wondering was, if you have every vendor in a committee of this type, would it be possible to accomplish anything? Is there enough similarity of interest that you could have a couple of people representing the interests of the vendors. Could there be a vendor committee who appoint two people to work or would that be possible? One of my colleagues from EPA pointed out that the vendors might trust one another but they wouldn't trust us.

M. Joss - What would be the chances of us, if you are trying to establish protocol, coming up with a task group that would come up with several, three leach tests, and three type of compression type tests and come up some kind of questionnaire and have a voting type system where after you evaluate these protocols and each vendor gets a shot to say, "In order of preference, of these leach tests I think this is my first, second choice". Establish a point system and at least you would come up with something most people could live with, I would hope.

N. Mossholder - I think maybe we would be boxing with shadows here. There may not be a problem. I suggest we just call a meeting of everybody that is interested in being on the task group and see how many show up.

P. Cote - We also have a protocol on the table now, and do we need a task force now or could we just go home and you read it and you answer back in writing, proposing a test that is not included in there. After looking at this information from everybody we might decide that there is no need for a task force. That would speed up the process if we could do it that way.

J. Conner - Just following up on what you started and what you just said, why not have all the vendors and also write to the other people who are not here. Tell them what happened and ask everybody to communicate back to you with not only the test protocols but their ideas about the whole program, whether they would be willing to participate, how they think the task group should be

set up and so on. I would think that would be the most efficient way to do it. If you want you could just take the statistics out of it and go with the majority on each point.

D. Friedman - My only problem is, if you have just a questionnaire and each one votes for which test they like the best, I think you really have no frame of reference as to why they selected one as best versus the other. Sometimes it's easiest to run, other times it models something they would rather model versus another one, and I would suggest that if we do anything like that then it sets out what the properties we are trying to determine. What are the questions we are trying to answer with each test. For example, if we are trying to determine the permeability of the material. The question is, how do we best determine the permeability of the samples. Then people can pick out whether they want tri-axial cell or fixed wall permeameter or whatever, and why they are recommending one versus the other. Then there is a better basis on which to come to a final selection.

A. Liem - I'm not sure what has been decided after the last 15 minutes. I thought we would form a task group or a task force or a committee to look at the test protocols.

M. Joss - I guess I have to agree here that if you can write a letter, Pierre, to the different Vendors and have them come back with their comments, you evaluate the information, send out a second letter and progress from there. I think you can accomplish what you want to accomplish in the most expeditious amount of time.

A. Liem - It still has to be decided which test methods would be applicable to different processes.

T. Bridle - We may have to do that again, we are going around and around in circles. I think the ideal thing would be to have a task force. Maybe we are not quite ready for that. Why don't we get comments from all the people here and we would also actually send as much information as we could to vendors that are not present here. Also ask for comments on everything, protocol, terms of reference, who they would like for a third party, how are we going to pay for

the thing, everything. Then we get that information back, we collate it somehow and then send out a response, and maybe at that point suggest another meeting of interested parties and that may be the start of a task force.

Unknown Speaker - I would suggest that when you do that, you include the comments you have gotten here this morning.

T. Bridle - Basically we have to get a form letter off to everybody, what is the timing. How soon could we get this information so that we could get a form letter off. A couple of weeks? By the end of this month we will get out something which as good a summary of what happened here, what we are looking for and ask for about a month turn-around time from people. The proceedings will not be available. We will have transcribed the important things.

E. Shuster - Another bit of information that would be useful to come with that would be the addresses and telephone numbers of the various participants here that would facilitate some conversations that might cut short some of the lengthy written comments. All the participants including the government people.

G. Fell - Two things, I think, one for David. How do you feel your agency and the state agencies are going to respond to this work up here? Secondly, what about cost. Who is bearing the cost for this? I think we as vendors should seriously look to that area.

D. Friedman - With respect to the first question, I think EPA, since we are very concerned about the same problems and same questions as our Canadian colleagues here. I would look to the studies to help us out just as the study that we have in its formative stages will be complementary with this study. One problem is that we still don't know what it is going to cost and how it will all fit together, but I would assume that the two governments will pay their share and the vendors will cover the costs of whatever they do.

G. Birkbeck - In regard to that point, I would rate that this would count as a technological development and there are federal, that is Canadian federal, funding programs that would assist any of the vendors in covering this,

providing they are a Canadian company. I don't know what the situation is in the United States.

D. Friedman - Not that!

K. Watkins - Neither Mark Joss nor I can commit our company at this point in time. I think this correspondence that you are going to be sending out will be helpful in reaching a decision on whether or not we want to participate or not. I think the question that is going to be in the back of our company's mind is, what are the implications going to be as far as regulatory agents are concerned. Is this going to be a piece of academic work? What is it going to lead to? I think that that is the question that my company is going to have before we get involved in it.

P. Hannak - My understanding is that it will have a bearing on the upcoming regulatory decisions.

J. Conner - A question. On these committees, task forces, whatever, we just talked about vendors, is anybody else going to be on this? Who else is going to be on this. Who is going to run it put it together? I presume, somebody in Canada is, but for example is USEPA going to be on it?

T. Bridle - As I said, I think that anybody who is going to be involved in that study has to be represented in some way, shape or form, and we really do have to identify somebody to act as the lead role. That probably will be either somebody from Environment Canada or from The Alberta Environmental Centre. We have to decide that amongst ourselves as to who that person will be. There has to be one focal point that everything sort of does go through. If there is a committee struck it will have to have representatives from EPA, Environment Canada, Alberta Environment, A.E.C. and vendors, etc. whoever is involved.

P. Hannak - We have a tentative agreement with the EPA that we are going to provide the interlaboratory data for the EPA study and we will get their data as well so both will be supplementary to each of us.

P. Grenier - Will you involve also provincial regulatory athorities in the task force? Here is Canada they are the people that are going to use the data.

T. Bridle - You are right. Last night we did have all the representatives of regulatory agencies meeting and I think, they will obviously be invited to attend. They may not wish to do so, but it will be their decision. It could become completely unwieldy if we end up with 10 provincial governments, two federal, 27 states.

H. Busbee - Your vendor list will be very short if you limit to the number of people who actually do work.

A. Liem - I was just wondering if each vendor can state what they think the objective of such a comparison study should be. I think we should find out here and now. I think we should have some indication now what they think the objective should be.

H. Mullen - I think there can only be one objective and that objective is does any given process meet the regulatory or the environmental requirements? If you eliminate the word comparison, I'm sure most of us would be a lot happier with the whole program. This is not a contest between vendors as we perceive it and if it is then I think you will see a lot of us dropping out of it. Does the system protect the environment adequately? That's all you need to know.

P. Cote - The goal of this exercise was to try develop standards that would be realistic with respect to the best available technology: not set arbitrary standards at the front end that we find no technology can meet or that all technologies can meet. That is, either too stringent or too loose. So we just stop the game for awhile and do this study on a scientific basis. We include several tests that might not become regulatory tests and we develop a data base that could help us choose the most useful test to be used as regulatory tools.

N. Mossholder - I don't think that there is any question that Hugh is correct in the overall global view that we need to determine what processes are capable of making these wastes acceptable for placement in the environment. In the context of this particular study, I think there are several objectives.

Number one is getting good, valid data test methods that can be used to assess this type of technology. A second objective in my mind, is to place what the technologies do in perspective with other forms of waste disposal such as untreated land disposal, kitty litter. Solidification on one end and materials that are commonly held by the lay person to be non-hazardous on the other end. You develop a spectrum and then place the properties of the treated solidified wastes in that spectrum in a way that scientists and lay people can evaluate for themselves, the relative degree of risk. From that you develop acceptance criteria and by nature I think the process is sequential, rather than simultaneous, to a certain extent and we have to recognize that.

T. Bridle - That's exactly what it is. It is a sequential process. It would be lovely if we could set right now a bunch of criteria and tests that we knew would adequately measure the criteria you are trying to measure and would give you the right answers. We are going through a sequential step that hopefully works. If everything works perfectly, we do everything right, we might be bloody lucky and all these things do fall out of the study. It may happen.

H. Mullen - Then I have to ask you and Dave, whether one of the objectives of this whole program is to determine whether a stabilization process can be used without any other protective measurements such as liners and leachate collection systems. In the States, it does not make any difference whether you stabilize or not, you have to put it in a lined landfill with a leachate collection system and there is no differentiation. So if you have that kind of protection what is the point of even bothering to analyze it and run the leachate.

P. Cote - The battery of tests that are included in the mismanaged scenario would tend to simulate what would happen if the waste is not put in a secure landfill with a liner, or if the waste is co-disposed with municipal garbage. That's why we have those two scenarios.

D. Friedman - To follow on to what Pierre just said. We have to keep in mind that one question is "To what degree does the waste need control?" and the second question is "In a given situation, what is going to be the insult to the

environment of that?" That is one problem. We keep talking about all the tests as if they are trying to determine the same thing. One thing I can see having to do is set up a clear cut differentiation, that maybe in one set of the tests what we are looking for is: Does this waste need control? And some kind of sliding scale that we can then use in the future from the regulatory aspect. We decide maybe we were too stringent or too loose. We will have a test that will give us a spectrum of numbers so we will know what is going to be the effect later on of changing numbers. The second group of tests is to determine the engineering properties on the site design. For example, the test you have on the run off, which tells you what's going to happen if you design the facility in such a way you are going to have run off like this. That's one type of property that's of concern, same with permeabilities. I think that is one area that will have to be addressed by the testing committee setting up the program.

P. Hannak - We are going to write the concensus as a letter to all of the vendors, asking their comments. We will present the discussion. What happened today and our suggestions as well, what we would like to do. We are going to ask for the suggestions of the vendors. We are going to form a committee and contact the vendors as we agreed on. Timing: that's maybe within 4 weeks of receiving the letters we would like to have an adequate response from the interested parties. Is it fair?

T. Bridle - We sort of agreed that by the end of November we would try to get this letter out, by early January get a response. We sift through the responses and see if there are some cohesive trends going thrcugh them. You are going to have to rely to a certain amount on our integrity to do that and then the need for a committee will either pop up clearly or we may have to go back to the drawing board a little bit more. There will definitely be another response to your response that will basically outline what we think is an acceptable approach to take from here on out.

C. Wiles - Don't limit your letter to just the vendors. I sort of got the feel that you were talking that this information would go to the vendors only.

J. Salloum - I was going to wait, and come up with a very statesmanlike summary of the whole thing but maybe you are ready for that now, are you? I was

merely corralling the microphone. I think what you people have done here today is a pretty sound professional and very potentially exciting piece of work that we can all be proud to have been involved in, once it is done. If we do things right, what we are going to have is an assessment of a technology, never mind the differences within the technology, but the assessment of a stabilization technology which can be used by all the regulatory authorities in the Unitied States and Canada. And if we do it right we'll have from the vendor's stand point one set of hurdles to leap through instead of potentially about a hundred and ninety five. I think this is potentially an excellent piece of work, but I hope we don't get caught up too much in little things. Let's at this point agree that the study concept is a good one. Let's agree that we are going to do it. Let's agree that we are going to have enough participation but not endless discussion. We are going to have enough participation from all the people who are involved, that we indeed can do a meaningful piece of work. I'm quite excited from our stand point as to the whole approach. If that's a general concensus, sort of a 60% view of everybody, which is about as much as you can hope for in this world. It's too early for the rest of my statesman-like remark, I will wait for a bit.

M. Wilson - I would like to do some back-patting first of all. Duane is right in saying that a really first rate job has been accomplished in the last couple of days. I was delighted to come across a little report the other day, and I want to quote you from this, because I think it is a good way to pat our province on the back. It is a National Research Council report, prepared by the task force on waste disposal. It is called "Geotechnical Aspects of Waste Disposal". Under the section which discusses present regulatory approaches in Canada it says, quote "Alberta is the most progressive province with respect to the hazardous waste program". I think what we have seen in the last two days is another step in that direction. I think we are trying to reduce what I perceive to be the main problem associated with this, and that's public uncertainty. We have taken another step toward reducing a degree of public uncertainty, so that the next time I am unfortunate to sit up in front of a public panel that knows nothing about this, and get fired at by people with all sorts of questions that I feel incompetent to answer, at least I know that there is some work going on in the background that I can quote and I can respond to. Thank you for coming. I think we have set the wheels in motion in the right direction and I am sure

that if we can get the appropriate funds coughed up from the different agencies that we are going to produce some work that we can really be proud of. A couple of other little things that I would like to point out to you that you may not be aware of. That is, that the vast majority of the administrative work in setting up this workshop was carried out by the senior secretary in our Wing, Barbara Anderson at the back, and her staff and I would like to thank her publicly for that. I think she has done a first rate job. We haven't had any foul-ups. I might add that this is the second such workshop she has organized in the last two months. Does anyone else want to add any final remarks?

J. Salloum - I am all through with with statesman-like remarks, Dr. Wilson, but what I would like to do is on behalf of Environment Canada and I think by concensus everybody else who attended, our sincere thanks for your hospitality and for a first-rate piece of work by you and your staff.

SECTION VIII

PROGRAMME AND OBJECTIVES

SECTION VIII

PROGRAMME

NOVEMBER 21

8:30	OPENING REMARKS	Dr. M. Wilson (AEC) Dr. J. D. Salloum (EC)
8:45	THE REGULATORY POINT OF VIEW Moderator - Bob Lane (EC)	
	Environment Canada	V. Douglas
	U.S. Environmental Protection Agency	D. Friedman
	Ontario Ministry of the Environment	R. Gotts
	Alberta Ministry of the Environment	K. Simpson
11:00	THE RESEARCH ASPECTS Moderator - C. Wiles (EPA)	
	Applicability of Solidification to Inorganic Wastes	P. Malone R. Larson (WES)
	Applicability of Solidification to Organic Wastes	Dr. M. Tittlebaum (LSU)
	Evaluation of the Long Term Stability of Solidified Wastes	P. Cote (WTC)
1:00	LUNCH	
2:00	CURRENT EXPERIENCE WITH TESTING OF SOLIDIFIED WASTES Moderator - Dr. A. Liem (AEC)	
	Chemfix Technologies Inc.	H. Buzbee
	Chem-Technics Inc.	J. Connor
	Dravo Lime Company	J. Thompson
	Envirosafe Corp.	H. Mullen
	Stablex (Canada) Inc.	P. Grenier
	Tricil Ltd.	J. M. Rousseaux
	U.S. Gypsum Company	M. Joss
4:00	ADJOURNMENT	
6:00	COCKTAIL AND DINNER	

NOVEMBER 22

9:00 PROPOSED WTC/AEC PROTOCOL AND COMPARISON STUDY

Moderator - P. Hannak (AEC)

WTC/AEC Assessment Protocol	P. Cote (WTC)
Terms of Reference for the Comparison Study	T. Bridle (WTC)

OPEN DISCUSSION:

Regulation aspects of the solidification technology

Proposed assessment protocol

Draft terms of reference for the comparison study

12:00 LUNCH

1:30 OPTIONAL VISIT OF THE ALBERTA ENVIRONMENTAL CENTRE

DEPARTURE

OBJECTIVES

Solidification of wastes is a relatively new technology for which regulatory guidelines have not yet been completely developed. Several questions remain unanswered with respect to the applicability of the technology to various waste streams and to the long term environmental stability of the solidified wastes. A first objective of this seminar is to provide a forum for the regulatory and research people to discuss these questions with the vendors of the technologies.

Environment Canada's Wastewater Technology Centre and the Alberta Environmental Centre are working on the development of an assessment protocol for solidified wastes. The protocol shall consist of a battery of tests to evaluate the solidified wastes under a wide range of environmental conditions. A second objective of this seminar is to discuss a first draft of the protocol to ensure its applicability and usefulness. When completed the protocol will be validated in a comparison study of waste solidified by participating vendors. The terms of reference for this comparison study will also be discussed at the seminar.

SECTION IX

LIST OF ATTENDEES

SECTION IX

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